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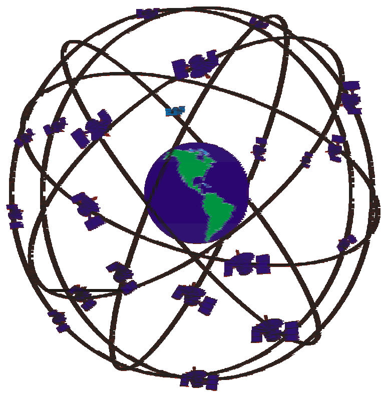

GLOBAL POSITIONING SYSTEM /INERTIAL NAVIGATION SYSTEM (GPS/INS) CORE TEST PLAN

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This document was developed by the members of the GPS Test Center of Expertise for the GPS Joint Program Office to be used to test GPS user equipment developed for DoD applications.

PREFACE

This Core Test Plan (CTP) is one of a family of Core Test Plans (CTPs) issued under the authority of the Global Positioning System (GPS) Joint Program Office. These CTPs describe the core test methodology, test beds, test methods, and analysis methods required to characterize and verify the performance of GPS receivers, Inertial Navigation Systems (INS), and integrated GPS/INS systems. Additional Test Item categories, such as Handheld GPS, integrated Doppler/GPS and GPS antennas, additional test methodologies such as shipboard testing, may be issued in the future.

The primary GPS test organization for the Department of Defense (DoD) consists of a number of Test Agencies from the various military Services, organized into a Center of Expertise (COE), with each of the member Test Agencies having unique test capabilities. In supporting the GPS Joint Program Office by testing DoD GPS receivers, the COE provides effective and efficient testing while minimizing duplication of testing. The Test Agencies currently included in the COE are:

Responsible Test Organization (RTO) - 46th Test Group, 746thTest Squadron

Participating Test Organization (PTO) - Space and Naval Warfare Systems Center (SPAWAR SC-SD)

PTO - U.S. Army Electronic Proving Ground (EPG)

PTO - Naval Research Laboratory (NRL)

PTO - U. S. Army Yuma Proving Grounds (YPG)

PTO - Naval Air Warfare Center – Weapons Division (NAWC-WD)

PTO - US Army Communications - Electronics Command (CECOM); Command and Control Directorate (C2D)

The COE provides a comprehensive spectrum of laboratory, van, and flight test beds to satisfy customer test requirements. A variety of precision reference systems producing very accurate Time Space Position Information (TSPI) are employed to support accurate performance evaluations.

A non-COE user of these CTPs should understand that there might be areas where the scope and terminology of a CTP are not completely applicable, especially in the testing of equipment intended for commercial application. There also may be differences in design, in which all functions or capabilities described in a CTP do not exist in the item being tested. Also, it is likely that a user's test program may be much more limited than one conducted by the DoD. In these cases, it is the responsibility of the tester to select a subset of the included tests to meet the needs of his/her test program, as well as the development of additional tests to meet specific design criteria or applications. As a minimum, these CTPs can then serve as a guide for developing detailed plans for testing functions and performance areas of a particular Test Item.

ACRONYMS

AC	Alternating Current
AFMC	Air Force Material Command
ASCC/NATO	Air Standardization Coordinating Committee/North Atlantic Treaty Organization
BARO	Barometric
BATH	Best Available True Heading
BIT	Built In Test
C/No	Carrier to Noise Ratio
COE	Center of Expertise
CTP	Core Test Plan
DoD	Department of Defense
EHE	Estimated Horizontal Error
EIA	Enhanced Interrupted Alignment
E/W	East/West
FOM	Figure of Merit
F3	Form, Fit, and Function
GC	Gyrocompass
GDOP	Geometric Dilution of Precision
GPS	Global Positioning System
Hz	Hertz (Frequency)
IFA	In Flight Alignment
INS	Inertial Navigation System
I/O	Input/Output
JPO	GPS Joint Program Office
N/S	North/South
PTO	Participating Test Organization
PVT	Position, Velocity, and Time
RF	Radio Frequency
RPER	Radial Position Error Growth Rate
RTO	Responsible Test Organization

SH	Stored Heading
SNU	Standard Inertial Navigation Unit
SV	Satellite Vehicle
TSPI	Time-Space-Positioning-Information
URA	User Range Accuracy
USAF	United States Air Force

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INTRODUCTION

PURPOSE

The synergistic navigation properties of Global Positioning System (GPS) receivers and Inertial Navigation Systems (INS) have resulted in a large demand for Integrated GPS/INS installations. Receiver components have shrunk to circuit card or chip sizes, and by sharing power supplies, I/O interfaces, smoothing filters, and enclosures with an INS, there are few weight, power and cost penalties for including a GPS receiver with most INSs. Accordingly, this CTP addresses basic testing guidelines for Integrated GPS/INS systems, specifically "tightly coupled" GPS/INS systems. For the purposes of this document, a tightly coupled system is one that shares a common integration filter, with the GPS information not only feeding the navigation solution output, but also being used to continuously update the INS's internal position data. Additionally, in a tightly coupled system the INS-derived velocity data are not only delivered to the navigation solution output, but are also provided to the GPS to support its internal predictive functions.

This CTP has been developed to satisfy a number of needs relating to Integrated GPS/INS. First, it serves as a reference document for the DoD Test agencies that make up the GPS Center of Expertise (COE), so that a baseline level of agreement will exist whenever a multi-agency Integrated GPS/INS test program is undertaken. Second, it is available for distribution to COE customers, to provide an overview of the type and level of GPS/INS testing available and recommended. Third, it is intended to be distributed freely to all agencies that acquire Integrated GPS/INS systems, to be a reference document for the development of individual Test Plans. Fourth, it serves as a training document for newly assigned test engineers at the various Test Agencies.

BACKGROUND

The nature and scope of any test program is derived from the test program's purpose and the Test Item type. This CTP describes the recommended testing to achieve a thorough evaluation of specific portions of Integrated GPS/INS systems, typical of that conducted by DoD agencies. The Standard Inertial Navigation Unit (SNU) 84-1, Specification for USAF Standard Form, Fit, and Function (F3) Medium Accuracy Inertial Navigation Unit, Rev. D, was used as a guide for the development of the INS portions of this CTP and is the source of the definitions of terms relating to inertial systems, such as Gyrocompass Alignment, Enhanced Interrupted Alignment, and others. The user is cautioned to ensure that the specifications applicable to the unit being tested are substituted and the procedures accordingly modified. This CTP also discusses test beds, test methods, and analytical methods associated with various test program categories and Test Item types.

AUTHORITY

The Air Force Material Command (AFMC) has designated the 46th Test Group, 746 Test Squadron as the Responsible Test Organization (RTO) for NAVSTAR GPS User Equipment effective 1 October 1991. Participating Test Organizations (PTOs), through the RTO, will conduct testing of GPS User Equipment for the NAVSTAR GPS Joint Program Office (JPO). The roles and responsibilities of the JPO, RTO, and PTOs are specified in Air Force Instruction 99-101.

TEST PROGRAM CATEGORIES

Within the DoD, test programs are generally categorized by the intent of the testing and the use to which the results will be put. The distinction within the categories also includes the type of source documentation against which the Test Item is evaluated as well as the rigor of the evaluation. These test program categories are generally defined as follows:

A. Certification - An extensive assessment of a Test Item's compliance with a design and/or performance specification. The test program must be sufficient to support a recommendation on the Test Item's readiness for milestones such as limited or full rate production or operational use, with results presented at a prescribed level of confidence.

B. Performance Verification - An assessment of the Test Item's compliance with a selected subset of design and performance specifications. Specification compliance must be evaluated with a prescribed level of confidence.

C. Source Selection - The acquisition and interpretation of sufficient functional and performance data to support a source selection decision. Selection criteria may include performance specifications, capability estimates, or other designated criteria.

D. Concept Demonstration - A demonstration of the viability of a Test Item design or concept.

TEST CONSIDERATIONS

Various DoD test agencies have conducted INS testing for more than 30 years. During this time, they have developed an extensive technical legacy of test considerations. This legacy is reflected in the specifics of the INS tests contained in this CTP. Some of these considerations are mentioned herein to assist a Test Manager in understanding the complexity of developing a comprehensive GPS/INS test program.

- **Security Considerations.** This CTP is primarily intended to address the testing of authorized GPS/INS receivers, namely those that are capable of receiving the encrypted Y-code. Although primary GPS testing is discussed in the GPS Receiver CTP (CTP-01-2002), the tester may well need to be handling crypto material to complete the testing herein. The tester must be fully cognizant of all security policies, both for simulator and field testing.

- Test Assumptions. This CTP assumes that a complete program of manufacturer's in-plant testing has already been satisfactorily completed. Accordingly, the CTP does not address low-level testing such as software verification and validation. This CTP addresses both the testing of the basic functionality and performance of the INS subsection, as well as the tests associated with its integrated functioning as a GPS/INS. It is assumed that the GPS Receiver CTP (CTP-01-2002) has been used to develop and complete a test program for the GPS subsystem. Before testing an integrated GPS/INS, it would be prudent to understand the functionality and performance of each subsystem and determine if the set is capable of being operated in the modes described in the tests in this document, even if it is nonstandard operation. The manufacturer's guidelines for causing the GPS/INS to function with only one subsystem operating MUST be followed. Simplistic disabling methods, such as shielding the GPS antenna will most likely result in test data not indicative of the INS's true performance. Also, if the INS subsystem being tested is designed to be used with barometric aiding, it is assumed that valid baro-aiding is provided for all testing.

- Simulation. The laboratory tests described in this document are generally of two kinds. First, there is “real-world” stimulation of the inertial sensors of the integrated GPS/INS unit. By using various laboratory “test tables” to simulate motion and thus accelerometer and angular inputs, these tests verify the functionality of the inertial sensor, its calibration and initialization, and the correct integration of the inertial measurements to produce a navigation solution. Second, there are tests that use an integrated GPS/inertial simulator to verify the GPS receiver and GPS/inertial measurement processing. These tests do not exercise the inertial sensor. The simulator creates inertial sensor output measurements (delta Vs and delta thetas) that are synchronized with the simulated GPS RF signal, and injects them into the navigation processor as if they had been provided by the inertial sensor. By conducting both kinds of laboratory tests all three major components are tested: the inertial sensor, the GPS receiver and the navigation processor.

The GPS Receiver CTP (CTP-01-2002) describes more extensive simulator testing of a GPS Receiver, and the philosophy of GPS simulator testing. For background but not direction, Annex A provides information on configuring a GPS simulator to conduct one specific GPS-only test.

- Data Analysis and Reporting Considerations. The data collected and reported from testing should be in a form that easily supports understanding by the targeted readers of the test report and assists in determining conclusions to be derived from the test results. Essential to this is the measurement units in which the data are reported. Since different measurement units are applicable to different users and programs, this CTP will not mandate units to be used. However, for tests conducted by members of the DoD Center of Expertise (COE), data will be reported in the units used in the Test Item’s requirements or compliance document for the particular test program.

This could be the specification, Operational Requirements Document, Interface Control Document or other documentation. The use of these standard measurement units will allow easy comparison of data and results between two or more test agencies, and will allow simple evaluation of results against the test requirements.

The number of test samples or tests is not specified in this Volume. Differences in application and criticality, as well as national and service requirements will affect this test consideration. Testers should consult their applicable source documents, such as The Specification for Evaluation of the Accuracy of Inertial Navigation Systems, Air Standard 70/11, ASCC/NATO, to determine this requirement. Annex B provides some background in statistical significance to help the tester determine the number of test repetitions that should be performed.

GPS/INS CORE TEST PLAN

The Global Positioning System (GPS)/Inertial Navigation System (INS) Core Test Plan (CTP) presents a list of laboratory and field tests that will evaluate a GPS/INS for functionality and performance. It is strongly recommended that the Introduction to this CTP be read and understood before developing a test plan from this CTP.

This CTP is divided into parts A and B, with the first describing tests intended to evaluate the INS subsection of a GPS/INS, and the second describing tests intended to evaluate the GPS/INS operating as a complete system. <u>It is assumed that the GPS Receiver CTP (CTP-01-2002) has been used to develop and complete a test program for the GPS subsystem</u>.

Each test contains four sections. They are: Test Objective(s), Special Test Equipment, Test Methods, and Data Collection and Analysis Methods. Related definitions and/or test philosophy is included where necessary to provide clarification. No attempt has been made to combine tests for maximum efficiency.

This CTP follows the test philosophy of "crawl, walk, run", in that the quickest, cheapest, most controlled tests are performed first. These would include laboratory tests, mobile field tests in a basic vehicle ("van"), and then flight tests. This allows for a slow development of information pertaining to the Test Item, and employs the least expensive test methodology first. Also, it is possible to characterize much of the performance, and many of the error sources of an INS, from laboratory testing. Accordingly, a large amount of laboratory testing is recommended. The "van" testing allows for the functional check of the installation/integration package, and initial field testing with dynamics, vibration, and temperature variances. Van testing can also be considered representative of the conditions experienced in any land vehicle and tailored to address specific performance requirements. The problem with field testing, apart from the high cost, is the potential lack of control of the test conditions and a lack of repeatability. The philosophy adopted for this CTP is to conduct field testing because: (1) the test cannot be conducted in the laboratory, (2) it is necessary to validate laboratory results as applicable to the real world, and (3) it is necessary to demonstrate the field capability of the Test Item. Within the series of flight tests, a similar approach is taken, conducting as much testing as possible on the "cargo" aircraft, which is relatively easy to access and instrument, and inexpensive to operate. Only specific tests within the unique flight regimes of the "fighter" and the "helicopter" are included in their respective areas. All of these test host vehicles would be used only when the Test Item was intended for multi-platform application. For any particular test program, the Test Manager will evaluate his requirements and available assets and determine the most practical and cost-efficient way to accomplish the needed test program.

PART A – INERTIAL NAVIGATION SUBSYSTEM

The tests in Part A are intended to evaluate the functionality and performance of only the INS portion of a GPS/INS system. As such, testers must become familiar with the Test Item manufacturer's directions for ensuring that, for many of the tests, the INS is operating without influence from the GPS and that the output data used reflects only the performance of the INS subsystem.

A.1. <u>INITIAL CHECKOUT</u>

These tests, replicated in each CTP, identify laboratory events to be conducted on every category of Test Item.

A.1.1. Configuration Verification.

This test is designed to ensure that the Test Item conforms to its identification, size, and weight requirements; appears secure enough to withstand testing; and has its ancillary and support equipment as needed for the envisioned test program. The configuration of the test site's test equipment will also be identified.

A.1.1.1. Test Objectives.

The test objectives are to verify the Test Item physical requirements and to initiate hardware and software configuration control.

A.1.1.2. Special Test Equipment.

None required.

A.1.1.3. Test Methods.

An audit of hardware and software assets will be performed upon delivery of each Test Item. The audit will gather, as a minimum, the following information:

a. Part and Serial Number
b. Software Version
c. Elapsed Time Reading
d. Size and Weight
e. Primary Power
f. Interfaces
g. Required Equipment Checklist.
h. Laboratory test equipment, including calibration date(s)
i. Laboratory test software version numbers

A.1.1.4. Data Collection and Analysis Methods.

Data will be reported in the measurement units of the requirements document. The weight, size, part numbers, serial numbers, and software version will be compared with configuration identification information provided by the manufacturer. Any discrepancies will be resolved.

A.1.2. Power-on Safety.

A.1.2.1. Test Objectives.
The test objective is to verify the safety of the test personnel, the laboratory equipment, and the Test Item, prior to the initial application of power.

A.1.2.2. Special Test Equipment.
None required.

A.1.2.3. Test Methods.
Each power, data, and RF connector of the Test Item will be identified and matched to its appropriate counterpart in the laboratory. Test personnel will verify:

a. the correct power connector is used,
b. the supplied voltage and frequency (AC circuits) matches the manufacturer's requirements,
c. there is adequate circuit protection,
d. the circuit impedance is correct (RF circuits).

Data connectors will be matched to the appropriate connector on laboratory equipment. Test personnel will take precautions to guard against static electricity damage. Leakage current will be measured on all exposed portions of the Test Item.

A.1.2.4. Data Collection and Analysis Methods.
Data will be reported in the measurement units of the requirements document. The manufacturer's documentation will be reviewed to ensure that each connection matches the configuration of the laboratory.

> *The remainder of Section A of this CTP identifies INS laboratory, van, and flight tests; and describes test objectives, test methods, and analysis methods. Paragraphs A.2.X present laboratory tests, paragraphs A.3.X present van tests, and paragraphs A.4.X present flight tests for inertial subsystem testing. Section B is similarly organized for an integrated GPS/INS system.*

A.2. LABORATORY

Table 1 identifies the test objective, responsible test and CTP paragraph for each test objective of this section. These tests are separated into Functional and Performance test objectives.

Table 1. INS Laboratory Tests

Test Objective	Responsible Test	CTP Test Paragraph
Functional Tests		
Demonstrate acceptable:		
MIL-STD-1553B Bus Operation	INS MIL-STD-1553B	A.2.1.1.
Synchro Operation	INS Synchro	A.2.1.2.
Lab Static Navigation Operation	Static Navigation	A.2.1.3.
Calibration Adequacy	Strapdown Calibration Adequacy	A.2.1.4.
Performance Tests		
Evaluate:		
Lab navigation performance following:		
Gyrocompass (GC) Alignment	GC Alignment	A.2.2.1.
Stored Heading (SH) Alignment	SH Alignment	A.2.2.2.
Enhanced Interrupted Alignment (EIA)	EIA Alignment	A.2.2.3.
Moving Base Alignment	Moving Base Alignment	A.2.2.4.
Best Available True Heading (BATH) Alignment	BATH Alignment	A.2.2.5.
Aided GC Alignment	Aided GC Alignment	A.2.2.6.
Scorsby Motion	Scorsby Motion	A.2.2.7.
Schuler Pump	Schuler Pump	A.2.2.8.
Attitude Accuracy	Attitude Accuracy	A.2.2.9.

A.2.1. Functional Evaluation of the Inertial Sensor.

A.2.1.1. INS MIL-STD 1553B.

A.2.1.1.1. Test Objective.

The test objective is to verify the proper generation and data content of the output of the Test Item's MIL-STD 1553B data bus, and to verify the Test Item's proper acceptance of MIL-STD 1553B input data.

A.2.1.1.2. Special Test Equipment.

An external 1553B bus controller is required for this test.

A.2.1.1.3. Test Methods.

An external bus controller will be used to generate input messages to the Test Item. The Test Item will be exercised in various modes to force its generation of MIL-STD 1553B output messages. MIL-STD 1553B data will be recorded. The proper acceptance and disposition of all commands will be verified. Mode transitions and proper indication of modes via the MIL-STD 1553B bus will be verified. All message formats will be reviewed to verify consistency with contractor documentation and applicable specifications.

A.2.1.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

- Test equipment identification and calibration dates.
- Test Item identification.
- Test Item navigation solution and time output at 1 Hz minimum.
- Test Item health status.
- Test Item MIL-STD 1553B data.

Data will be reported in the measurement units of the requirements document. The proper acceptance and disposition of all initialization parameters will be verified. Mode transitions and proper indication of modes via the MIL-STD 1553B bus will be verified. All message formats will be reviewed to verify consistency with contractor documentation and applicable specifications.

A.2.1.2. INS Synchro.

A.2.1.2.1. Test Objective.

The test objective is to verify that the Test Item synchro outputs provide attitude (roll, pitch, and heading) data that meet cockpit steering instrument requirements.

A.2.1.2.2. Special Test Equipment.

A three axis positioning table and flight instruments are required for this test.

A.2.1.2.3. Test Methods.
A synchro reference signal will be provided to the Test Item, and the Test Item will be rotated through roll, pitch, and heading. Synchro attitude outputs will be connected to both a synchro-to-digital converter and directly to flight instruments. The MIL-STD 1553B attitude data and digitized synchro attitude data will be collected.

A.2.1.2.4. Data Collection and Analysis Methods.
Data will be reported in the measurement units of the requirements document. The synchro-to-digital converter outputs and the flight instruments will be observed to detect sudden movement, biases, and errors. The synchro outputs and the MIL-STD 1553B attitude data will be compared to each other and to the synchro input data for accuracy.

A.2.1.3. Static Navigation.

A.2.1.3.1. Test Objective.
The test objective is to demonstrate acceptable static navigation performance.

A.2.1.3.2. Special Test Equipment.
A fixed test table is required for this test.

A.2.1.3.3. Test Methods.
The Test Item will be mounted on a test bed or test fixture in a stationary position. A full accuracy gyrocompass (GC) alignment will be accomplished, followed by a 2-hr navigation period.

A.2.1.3.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Zero-intercept, linear error estimators will be fit to the radial position error at the 60 and 120 minute data points. These will be used to determine the Radial Position Error Growth Rate (RPER). The root mean square (rms) velocity errors (east and north) will also be calculated and plotted.

A.2.1.4. Strapdown Calibration Adequacy.

A.2.1.4.1. Test Objective.
The objectives of this test are to determine if the inertial sensors are functioning properly, to estimate the gyro misalignment errors, gyro scale factors, accelerometer misalignments and biases, and to determine how well the INS is calibrated.

A.2.1.4.2. Special Test Equipment.

A three axis rate and positioning table is required for this test.

A.2.1.4.3. Test Methods.

The vertical axis of the Test Item will be mounted within ±3 arc minutes of the table inner axis. The Test Item will be GC aligned for the specified alignment time at ambient temperature, with a 0° heading. Following alignment, and after 5 minutes at the initial orientation, the system will be sequentially rotated to the 20 positions as defined in Table 2, with angular position for each rotation within ± 0.5º of the rotations. Rotation rates will be 18 ± 0.5º/second with the table programmed to dwell at each position for 5 minutes.

Table 2. Strapdown Calibration Adequacy Rotation Sequence

ROTATION	ORIENTATION AFTER ROTATION		
0. Initial Attitude	XN	YE	ZD
1. Plus 180º about N(X)	XN	YW	ZU
2. Plus 180º about N(X)	XN	YE	ZD
3. Plus 180º about E(Y)	XS	YE	ZU
4. Plus 180º about E(Y)	XN	YE	ZD
5. Plus 90º about N(X)	XN	YD	ZW
6. Plus 180º about N(X)	XN	YU	ZE
7. Plus 180º about N(X)	XN	YD	ZW
8. Plus 180º about W(Z)	XS	YU	ZW
9. Plus 180º about W(Z)	XN	YD	ZW
10. Plus 180º about D(Y)	XS	YD	ZE
11. Plus 180º about D(Y)	XN	YD	ZW
12. Plus 90º about W(Z)	XD	YS	ZW
13. Plus 180º about W(Z)	XU	YN	ZW
14. Plus 180º about W(Z)	XD	YS	ZW
15. Plus 180º about D(X)	XD	YN	ZE
16. Plus 180ºabout D(X)	XD	YS	ZW
17. Plus 90º about D(X)	XD	YW	ZN
18. Plus 180º about W(Y)	XU	YW	ZS
19. Plus 180º about W(Y)	XD	YW	ZN
20. Plus 90º about W(Y)	XS	YW	ZD

Note: The following orientation conventions are used in the above Table:
X - Strapdown X axis, toward aircraft nose
Y - Strapdown Y axis, toward aircraft right wing
Z - Strapdown Z axis, toward aircraft belly
N - North E - East
W - West U - Up
S - South D - Down

A.2.1.4.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The Test Item velocity (east, north, and up), attitude (heading, pitch, and roll), and time data from the 20 positions will be processed by a six-state Kalman filter to estimate acceleration errors in all three strapdown axes (X, Y, and Z) immediately before and after each rotation. A least squares fit to the strapdown error model will be used to estimate the residual calibration errors given in Table 3 from the acceleration error estimates. Estimates of the residual calibration errors derived from the test will be compared to the specified error budget or one derived from application requirements.

Table 3. Residual Calibration Errors

Error Source	**Units**
Gyro Scale Factor (X, Y, Z)	ppm
Gyro Misalignment (XY, XZ, YX, YZ, ZX, ZY)	arcmin
Accelerometer Bias (X, Y, Z)	micro-g's
Accelerometer Scale Factor Differences (X-Y, Y-Z, Z-X)	ppm
Accelerometer Misalignment (YX, ZX, ZY)	arcsec

A.2.2. Performance Evaluation of the Inertial Sensor.

While Functional Evaluation is usually closely controlled by product specifications, during Performance Evaluation testing the Test Manager must determine the appropriate conditions to apply to the Test Item.

A.2.2.1. GC Alignment.

A.2.2.1.1. Test Objective.

The test objective is to evaluate the position and velocity accuracy of the Test Item following a gyrocompass (GC) alignment, across the specified range of operating temperatures, in a controlled laboratory environment. This test will produce baseline performance data at the laboratory's latitude, and will help to identify any errors induced by the Test Item's installation and integration.

A.2.2.1.2. Special Test Equipment.

A temperature chamber is required for this test.

A.2.2.1.3. Test Methods.

The Test Item will be oriented on a N/S heading and maintained at the selected test temperature for a minimum of 2 hours prior to the initial test at that temperature. Test temperatures will span the specified Test Item temperature operating range. If the time between tests exceeds 4 hours, the Test Item will be maintained at the selected temperature a minimum of 2 hours before continued testing. Following a GC alignment, the Test Item will be switched to the navigation mode and allowed to navigate for a period of time appropriate for the Test Item's intended application, or as determined from its specification.

A.2.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates for each of the temperature regimes.

A.2.2.2. SH Alignment.

A.2.2.2.1. Test Objective.

The test objective is to evaluate position and velocity accuracy of the Test Item, following a Stored Heading (SH) alignment, across the specified range of operating temperatures.

A.2.2.2.2. Special Test Equipment.

A temperature chamber and a vertical axis positioning fixture are required for this test.

A.2.2.2.3. Test Methods.

Prior to the initial test at each temperature, the Test Item will be maintained at the designated test temperature for 2 hours. Test temperatures will span the Test Item temperature operating range provided in the specification. If the time between tests exceeds 4 hours, the Test Item will be maintained at the selected temperature a minimum of 2 hours before continued testing. The Test Item will be oriented with a 0° heading and a GC alignment will be performed. Following the GC alignment, the Test Item will be turned off for a prescribed time, turned on, and switched to SH alignment mode. After a prescribed SH alignment period, the Test Item will be switched into the navigation mode and allowed to navigate for a specified period. The length of time the Test Item will be in each mode will be time appropriate for the Test Item's intended application, or as determined from its specification.

A.2.2.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates for each of the temperature regimes. The position and velocity data will be evaluated against the specification and also against the results of the GC alignment.

A.2.2.3. Enhanced Interrupted Alignment (EIA).

Some inertial navigation units incorporate an Interrupted Align capability to enhance the functional operation of ground alignment. For Test Items with this capability, this test should be performed.

A.2.2.3.1. Test Objective.

The test objective is to evaluate Test Item static navigation performance after an EIA.

A.2.2.3.2. Special Test Equipment.

A vertical axis positioning fixture is required for this test.

A.2.2.3.3. Test Methods.

The Test Item will be oriented with a 0º heading and a GC alignment will be completed. At the end of the GC alignment, the Test Item will be switched to the navigation mode and, within a prescribed time period, will be rotated at least 70º from the initial heading. The heading change time will not exceed 10 minutes. The GC alignment mode will be reentered for a prescribed time period. Following the second alignment period, navigation mode will be reentered and the Test Item allowed to navigate for a time period appropriate for the Test Item's intended application, or in according to the specification.

A.2.2.3.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.2.2.4. Moving Base Alignment.

A.2.2.4.1. Test Objectives.
The test objective is to evaluate the effects of base motion on Test Item position and velocity accuracy during a GC alignment. This test will evaluate the Test Item's ability to align when subjected to worst-case wind loading during an on-aircraft alignment.

A.2.2.4.2. Special Test Equipment.
A horizontal axis vibration table is required for this test.

A.2.2.4.3. Test Methods.
The Test Item will be mounted on a N/S heading on a single axis vibration table. A GC alignment will be performed while the table undergoes a 1 Hz peak-to-peak east-west translation. In addition, a 2.0 cm fixed east-west translation over a 0.5-second period will be introduced. At the completion of the GC alignment, the Test Item will be placed in the navigation mode for a time appropriate for the Test Item's intended application, or as determined from its specification, to complete one test.

A.2.2.4.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.2.2.5. BATH Alignment.
The Best Available True Heading (BATH) alignment mode is a sub mode of the SH alignment mode and is not selectable. The BATH alignment mode can only be entered in two ways. One way is by inserting a True Heading, a Magnetic Heading, or present position. The other way is if the prerequisites for the SH alignment mode are not satisfied, the INS will automatically initiate a BATH alignment using the stored heading and position from the previous navigation run.

A.2.2.5.1. Test Objective.
The test objective is to evaluate the Test Item position and velocity accuracy following a BATH alignment.

A.2.2.5.2. Special Test Equipment.
A vertical axis positioning fixture is required for this test.

A.2.2.5.3. Test Methods.
The Test Item will be oriented with a 0º heading and a full performance GC alignment will be performed. Following the GC alignment the Test Item will be:

a. Switched to the navigation mode and allowed to navigate for a prescribed time.

b. Turned off for a length of time, as determined from the specification, after recording the heading error. The Test Item will be rotated to a new true heading of 90º or 270º. The true heading will be entered into the Test Item.
c. Turned on.
d. Switched to the SH alignment mode.

After the SH alignment is complete, the Test Item will be switched into the navigation mode and allowed to navigate for a length of time appropriate for the Test Item's intended application, or as determined from its specification.

A.2.2.5.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The heading error at step b. above will be evaluated to ensure a valid GC alignment had been completed. Position, velocity and heading error data will be evaluated against the specified allowable error rates.

A.2.2.6. Aided GC Alignment.

A.2.2.6.1. Test Objectives.

The test objective is to evaluate the Test Item position and velocity accuracy following an alignment aided by another, non-GPS navigation source. This test will determine if the Test Item is accepting initial position information from the aiding source.

A.2.2.6.2. Special Test Equipment.

A vertical axis positioning fixture and a non-GPS aiding source are required for this test.

A.2.2.6.3. Test Methods.

The Test Item will be oriented with a 0° heading and an aided alignment will be performed. Following the alignment, the Test Item will be switched to an unaided navigation mode and allowed to navigate for a specified period to complete the test.

A.2.2.6.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.2.2.7. Scorsby Motion.

A.2.2.7.1. Test Objective.

The test objective is to evaluate the Test Item position and velocity accuracy while undergoing Scorsby motion. Scorsby motion is a cyclic rotation around all three axes, at the same frequency but out of phase, so that “coning” motion is generated, usually about two of the axes. Scorsby motion imparts only oscillation and no net attitude displacement.

A.2.2.7.2. Special Test Equipment.

A Scorsby table is required for this test.

A.2.2.7.3. Test Methods.

The Test Item will be mounted on a Scorsby table. The system will be GC aligned and switched to the navigation mode. The Scorsby table will be off during the alignment process and activated after the Test Item is in the navigation mode. The Scorsby table will be activated at a suggested frequency of six cycles per minute at +/- 3° amplitude, and the INS will be allowed to navigate for a specified period. The length of time for the test shall be appropriate for the Test Item's intended application, or as determined from its specification, or for two Schuler cycles.

A.2.2.7.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.2.2.8. Schuler Pump.

A.2.2.8.1. Test Objectives.

The test objective is to evaluate the Test Item’s performance when the level axis gyro and accelerometer bias, noise and composite errors are excited.

A.2.2.8.2. Special Test Equipment.

A vertical axis test fixture is required for this test.

A.2.2.8.3. Test Methods.

The Test Item will be mounted on the vertical axis test fixture with a 0º heading. The Test Item will be GC aligned, switched to navigation mode, and then rotated 180º about the vertical axis. Data will be collected for 42.2 Minutes (1/2 Schuler cycle) and the Test Item will be rotated 180º back to the initial heading where data will continue to be collected for 84.4 minutes. The above procedures will be repeated with an initial heading of 90º.

A.2.2.8.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.2.2.9. Attitude Accuracy.

A.2.2.9.1. Test Objective.

The test objective is to evaluate the Test Item's attitude accuracy during navigation. The rotation amounts and increments below are suggested values that have been found effective to identify attitude errors.

A.2.2.9.2. Special Test Equipment.

A three axis test table is required for this test.

A.2.2.9.3. Test Methods.

The Test Item will be mounted on the inner gimbal of a three-axis table with a 0° heading. The Test Item will be GC aligned and switched to the navigation mode. The Test Item will be rotated 360° in azimuth in increments of 20°, rotated ± 90° in pitch in increments of 5°, and rotated ± 90° in roll in increments of 5°. The roll, pitch, and azimuth rotations are performed sequentially, not simultaneously. The rotation rates will be determined from the specification. One hour after entry into the navigation mode, the orientations will be repeated to observe any growth of attitude error over time.

A.2.2.9.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The Test Item attitude errors are defined as the difference between the Test Item attitude measurement and the precision table readout. Azimuth, pitch, and roll errors will be calculated, plotted, and compared to the system performance requirements. Significant trends or patterns observed in the attitude errors will be investigated.

A.3. VAN

For systems intended to be used in a ground vehicle application, it is recommended that the installation in the van be representative of the ultimate application, including signal levels, vibration, temperature, etc. The Test Manager should ensure that test methods employed in the laboratory are replicated as closely as possible in the field, to ensure that any observed changes in performance are not induced by the procedures. A suitable truth source, such as a surveyed course or a Time-Space-Positioning-Information (TSPI) system is needed to evaluate van tests. Table 4 summarizes the INS van tests, identifies the test objectives, the tests, and the CTP test description paragraph associated with each test. These tests are separated into Functional and Performance test objectives:

Table 4. INS Van Tests

Test Objective	Responsible Test	CTP Test Paragraph
Functional Tests		
Demonstrate acceptable:		
Van Static Navigation Operation	Van INS Static Navigation	A.3.1.1.
Performance Tests		
Evaluate performance following:		
Gyrocompass (GC) Alignment	Van GC Alignment	A.3.2.1.
In-Flight Alignment (IFA)	Van INS IFA	A.3.2.2.

A.3.1. Van Functional.

A.3.1.1. Van INS Static Navigation.

A.3.1.1.1. Test Objectives.

The test objectives are to verify that the Test Item is functioning properly as installed in the van and to determine if the Test Item navigation solution is being generated, displayed, and recorded.

A.3.1.1.2. Special Test Equipment.

None required.

A.3.1.1.3. Test Methods.

The Test Item will be turned on, GC aligned, and switched to the navigation mode with the van static over a surveyed benchmark. The Test Item will be allowed to navigate for 2 hours.

A.3.1.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The data will be reviewed to determine that the Test Item is functioning properly. The Test Item navigation solution will be compared with the static surveyed benchmark coordinates to verify the system is navigating within specification.

A.3.2. Van Performance.

A.3.2.1. Van GC Alignment.

A.3.2.1.1. Test Objective.

The test objective is to evaluate the Test Item position and velocity accuracy under the dynamic velocity and vibration conditions typical of a van environment, following a GC alignment.

A.3.2.1.2. Special Test Equipment.

None required.

A.3.2.1.3. Test Methods.

Each test will begin with the van parked over a surveyed benchmark and the INS oriented with either a N/S or E/W heading. Following a GC alignment, the Test Item will be switched into the navigation mode and the van will depart the surveyed benchmark and proceed along a ground course for a test period of at least two hours. The van will return to the initial surveyed benchmark at the end of each test.

A.3.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.3.2.2. Van In Flight Alignment (IFA).

A.3.2.2.1. Test Objective.

The test objective is to evaluate the Test Item position and velocity accuracy following an IFA in the van dynamic environment. This test is applicable to GPS/INSs that are able to accept aiding other than GPS.

A.3.2.2.2. Special Test Equipment.

None required.

A.3.2.2.3. Test Methods.

Each test will begin with the van parked over a surveyed benchmark and the INS oriented with either a N/S or E/W heading. A GC alignment will be conducted and the Test Item will be switched to an unaided navigation mode. The van will depart the surveyed benchmark and proceed along a ground course. After a period of time appropriate for the Test Item's intended application, or as determined from its specification, the Test Item will be commanded to perform an IFA, aided by another, non-GPS navigation source. The Test Item will be switched to an unaided navigation mode for the duration of the test. The van will return to the initial surveyed benchmark at the end of each test.

A.3.2.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The Test Item position and velocity data during the period of unaided navigation following the IFA will be evaluated against the specified allowable error rates.

A.4. FLIGHT

A suitable truth source, such as a Time-Space-Positioning-Information (TSPI) system or a tracking system, is needed to evaluate flight tests. In addition, the Test Manager must plan for the flight phase with care. If testing is to be done on multiple aircraft types, the test package should not be changed to accommodate installation issues, in order to ensure compatibility of test results. If the installation is to be in an aircraft that is representative of the ultimate application, its installation should replicate that installation as much as possible. However, a test installation also must accommodate a data recording capability usually not included in an operational installation. In all cases, advance concern must be given to mounting, power availability, antenna placement, wiring, and maintenance access, especially in more compact aircraft such as the "fighter". Table 5 identifies INS flight tests, identifies the test objectives, test, and CTP test description paragraph associated with each test. These tests are separated into Functional and Performance objectives:

Table 5. INS Flight Tests

Test Objective	Responsible Test	CTP Test Paragraph
Functional Tests		
Demonstrate acceptable:		
Flight Static Navigation Operation	Flight INS Static Navigation	A.4.1.1.
Performance Tests		
Evaluate Performance following:		
Gyrocompass (GC) Alignment	Cargo Aircraft GC Alignment	A.4.2.1.
Enhanced Interrupted Alignment (EIA	Cargo Aircraft EIA	A.4.2.2.
In-Flight Alignment	Cargo Aircraft INS IFA	A.4.2.3.
Fighter Flight Profiles	Fighter Flight Profiles	A.4.2.4.
Helicopter Flight Profiles	Helicopter Flight Profiles	A.4.2.5.

A.4.1. Flight Functional

A.4.1.1. Flight INS Static Navigation.

A.4.1.1.1. Test Objectives.

The test objectives are to verify that the Test Item is functioning properly as installed in the aircraft and to determine that the Test Item navigation solution is being generated, displayed, and recorded.

A.4.1.1.2. Special Test Equipment.

None required.

A.4.1.1.3. Test Methods.

The Test Item will be turned on, GC aligned, and switched to the navigation mode with the aircraft parked over a surveyed benchmark. The Test Item will be allowed to navigate for 2 hours.

A.4.1.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. The data will be reviewed to determine that the Test Item is functioning properly. The Test Item navigation solution will be compared with the static surveyed benchmark coordinates to verify the system is operating properly.

A.4.2. Flight Performance.

A.4.2.1. Cargo Aircraft GC Alignment.

A.4.2.1.1. Test Objective.

The test objective is to evaluate Test Item position and velocity accuracy following a GC alignment in a cargo aircraft flight environment.

A.4.2.1.2. Special Test Equipment.

None required.

A.4.2.1.3. Test Methods.

Each test will begin over a surveyed benchmark. To induce a maximum error, the Test Item should be aligned with the aircraft 90º from the primary direction of the flight path. Following a GC alignment, the aircraft will be switched to the navigation mode and depart the surveyed benchmark and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

A.4.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.4.2.2. Cargo Aircraft Enhanced Interrupted Alignment (EIA).

A.4.2.2.1. Test Objective.

The test objective is to evaluate Test Item position and velocity performance after an EIA has been performed in a cargo aircraft flight environment. This test is needed only if the Test Item does not have a zero-velocity update capability.

A.4.2.2.2. Special Test Equipment.

None required.

A.4.2.2.3. Test Methods.

The vehicle with the Test Item installed shall be oriented in any direction and a GC alignment shall be completed. At the end of the GC alignment, the Test Item shall be switched to the navigation mode and the vehicle shall be taxied to a new heading at least 70º from the initial heading, within 10 minutes. When stopped over a surveyed benchmark, the GC alignment mode will be reentered for a prescribed time period. The vehicle must be completely stopped prior to re-entering GC alignment and remain stopped throughout the duration of the alignment. Following a specified GC alignment period, the aircraft will be switched back to a navigation mode and depart and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

A.4.2.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.4.2.3. Cargo Aircraft INS IFA.

A.4.2.3.1. Test Objective.
The test objective is to evaluate Test Item position and velocity accuracy following an in-flight alignment (IFA) in a cargo aircraft flight environment. This test is applicable to INSs that are able to accept aiding other than GPS.

A.4.2.3.2. Special Test Equipment.
None required.

A.4.2.3.3. Test Methods.
Each test will begin over a surveyed benchmark. A GC alignment will be conducted and the Test Item will be switched to an unaided navigation mode. The aircraft will depart the surveyed benchmark and proceed on the selected flight profile. After a period of time appropriate for the Test Item's intended application, or as determined from its specification, the Test Item will be commanded to perform an IFA, aided by another, non-GPS, navigation source. The Test Item will be switched to an unaided navigation mode for the duration of the test. The aircraft will return to the initial surveyed benchmark at the end of the test.

A.4.2.3.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.4.2.4. Fighter INS Flight Profiles.

A.4.2.4.1. Test Objective.
The test objective is to evaluate Test Item position and velocity accuracy in a fighter flight environment.

A.4.2.4.2. Special Test Equipment.
None required.

A.4.2.4.3. Test Methods.
For fighter testing, flight profiles should be selected that will subject the Test Item to representative end-application dynamics, or to the limits of the test platform. Each test will begin over a surveyed benchmark. Following a GC alignment, the aircraft will depart the surveyed benchmark and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

A.4.2.4.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

A.4.2.5. Helicopter INS Flight Profiles.

A.4.2.5.1. Test Objective.
The test objective is to evaluate the test item's position and velocity accuracy in a helicopter flight environment.

A.4.2.5.2. Special Test Equipment.
None required.

A.4.2.5.3. Test Methods.
For helicopter testing, flight profiles should be selected that will subject the Test Item to representative end-application dynamics, or to the limits of the test platform. Each test will begin over a surveyed benchmark. Following a GC alignment, the helicopter will depart the surveyed benchmark and proceed along the selected flight profile. The test item will be baro-aided for the duration of the flight. The helicopter will return to the surveyed benchmark at the end of each test.

A.4.2.5.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Data will be reported in the measurement units of the requirements document. Position and velocity data will be evaluated against the specified allowable error rates.

PART B. INTEGRATED GPS/INS SYSTEM

B.1. <u>Initial checkout</u>

These tests, replicated in each CTP, identify laboratory events to be conducted on every category of Test Item.

B.1.1. Configuration Verification.

This test is designed to ensure that the Test Item conforms to its identification, size, and weight requirements; appears secure enough to withstand testing; and has its ancillary and support equipment as needed for the envisioned test program. The configuration of the test site's test equipment will also be identified.

B.1.1.1. Test Objectives.

The test objectives are to verify the Test Item physical requirements and to initiate hardware and software configuration control.

B.1.1.2. Special Test Equipment.

None required.

B.1.1.3. Test Methods.

An audit of hardware and software assets will be performed upon delivery of each Test Item. The audit will gather, as a minimum, the following information:

- a. Part and Serial Number
- b. Software Version
- c. Elapsed Time Reading
- d. Size and Weight
- e. Primary Power
- f. Interfaces
- g. Required Equipment Checklist.
- h. Laboratory test equipment, including calibration date(s)
- i. Laboratory test software version numbers

B.1.1.4. Data Collection and Analysis Methods.

Data will be reported in the measurement units of the requirements document. The part numbers, serial numbers, and software version will be compared with configuration identification information provided by the manufacturer. Any discrepancies will be resolved.

B.1.2. Power-on Safety.

B.1.2.1. Test Objectives.

The test objective is to verify the safety of the test personnel, the laboratory equipment, and the Test Item, prior to the initial application of power.

B.1.2.2. Special Test Equipment.

None required.

B.1.2.3. Test Methods.

Each power, data, and RF connector of the Test Item will be identified and matched to its appropriate counterpart in the laboratory. Test personnel will verify:

a. the correct power connector is used,
b. the supplied voltage and frequency (AC circuits) matches the manufacturer's requirements,
c. there is adequate circuit protection,
d. the circuit impedance is correct (RF circuits).

Data connectors will be matched to the appropriate connector on laboratory equipment. Test personnel will take precautions to guard against static electricity damage. Leakage current will be measured on all exposed portions of the Test Item.

B.1.2.4. Data Collection and Analysis Methods.

Data will be reported in the measurement units of the requirements document. The manufacturer's documentation will be reviewed to ensure that each connection matches the configuration of the laboratory.

The remainder of Section B of this CTP identifies GPS/INS laboratory, van, and flight tests; and describes test objectives, test methods, and analysis methods. Paragraphs B.2.X present laboratory tests, paragraphs B.3.X present van tests, and paragraphs B.4.X present flight tests.

B.2. LABORATORY

Table 6. Laboratory Tests of the Integrated GPS/INS

Test Objective	Responsible Test	CTP Test Paragraph
Functional Tests		
Demonstrate acceptable:		
Static Navigation	GPS/INS Static Navigation	B.2.1.1.
Aided Alignment	GPS/INS Aided Alignment	B.2.1.2.
Degraded Operation	GPS/INS "Failsoft"	B.2.1.3.
Performance Tests		
Evaluate performance following:		
GPS/INS Performance	GPS Aided Navigation Performance	B.2.2.1.
Satellite Reacquisition	Satellite Reacquisition	B.2.2.2.
Figure of Merit Accuracy Test	Figure of Merit Accuracy	B.2.2.3.
Characterization of Multipath Effect	Multipath Characterization	B.2.2.4.
Degraded Operations	INS Aided Degraded Operating Conditions	B.2.2.5.

B.2.1. Functional Tests.

B.2.1.1. GPS/INS Static Navigation.

B.2.1.1.1. Test Objective.

The test objectives are to verify that the Test Item is functioning properly in a non-dynamic environment, that the GPS solution is bounding the INS error, and that the Test Item navigation solution is being generated and displayed. The implementation of the integration filter can be examined by reviewing the integrated navigation solution along with the subsystem navigation solutions.

B.2.1.1.2. Special Test Equipment.

A fixed position test table or test fixture and either a GPS simulator or live Space Vehicle (SV) signals are required for this test.

B.2.1.1.3. Test Methods.

a. Simulator Configuration – If used, the GPS simulator will be configured to provide a nominal constellation at the laboratory location. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution – The Test Item will be turned on in a static laboratory environment. The Test Item will be allowed to complete a GPS-aided INS alignment as well as a complete GPS initialization. The duration of the test will be a function of the expected mission duration of the Test Item, but not less than one Schuler cycle (84.4 minutes). All configurations/modes of the Test Item will be tested. This will include the loss of GPS signals for varying periods to evaluate the performance of the integration filter.

B.2.1.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.

Test Item identification.

Test Item navigation solution and time output at 1 Hz minimum.

Test Item health status and state or tracking codes.

Test Item internal accuracy estimators (Figure of Merit (FOM), Estimated Horizontal Error (EHE), etc.)

Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The data will be reviewed to determine that the Test Item is functioning properly. The Test Item navigation solution will be compared with the laboratory coordinates to verify the system is operating properly. Data will be evaluated to ensure that the navigation solution is not increasing over time.

B.2.1.2. GPS/INS Aided Alignment.

B.2.1.2.1. Test Objective.

The test objective is to evaluate the Test Item's position and velocity accuracy following an alignment aided by its internal GPS. A second test will be conducted to allow the Test Item to conduct a normal start, with both GPS initialization and INS alignment proceeding simultaneously.

B.2.1.2.2. Special Test Equipment.

A fixed test table and either a GPS simulator or live SV signals are required for this test.

B.2.1.2.3. Test Methods.

a. Simulator Configuration – If used, the simulator will be configured to provide a nominal constellation at the laboratory location. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution – The Test Item will be allowed to complete a GPS initialization with the INS portion disabled. The INS will be enabled and allowed to complete a GC alignment, and then switched to the navigation mode. Following alignment, the duration of the test will be a function of the expected mission duration of the Test Item, but not less than one Schuler cycle (84.4 minutes). The test will be repeated with the Test Item being allowed to conduct a normal start of both GPS and INS simultaneously.

B.2.1.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Position and velocity data from both the integrated system and the INS-only will be evaluated. The two data sets will be compared to ensure that the INS alignment used the GPS aiding in its alignment.

B.2.1.3. GPS/INS "Failsoft".

B.2.1.3.1. Test Objective.

The test objective is to ensure that the Test Item properly defaults to its required operating mode following the failure of either subsystem.

B.2.1.3.2. Special Test Equipment.

A fixed test table and either a GPS simulator or live SV signals are required for this test.

B.2.1.3.3. Test Methods.

a. Simulator Configuration – If used, the simulator will be configured to provide a nominal constellation at the laboratory location. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution – After being aligned and initialized, and having achieved a stable navigation solution, the GPS and the INS subsystems will be made to cease to operate, individually, in two independent test events. The specific procedures for inducing these failures must be determined based on the Test Item's specific design. Merely eliminating the SV signal is not sufficient to induce a GPS failure. Data from each subsystem and the integrated navigation solution will be recorded.

B.2.1.3.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The data will be analyzed to ensure that the Test Item outputs correct navigation data as required by its specification, and that any required alerting messages are properly transmitted.

B.2.2. Performance Evaluation.

Section A.2.2. focused on evaluating the inertial sensors, and the navigation processor that computes a navigation solution from the inertial measurements. Those tests required the inertial sensor to make real measurements. This section's performance tests evaluate the GPS receiver and navigation processor by stimulating both with simulated data. A GPS/inertial simulator is used to generate a GPS RF signal and synchronized inertial measurements. The inertial measurements are introduced into the navigation processor as if the real inertial sensor had generated them. The GPS receiver tracks the simulated RF and provides code and carrier measurements and timing information to the navigation processor. The navigation processor calculates a navigation solution by combining the information contained in the GPS and inertial measurements. The following tests are designed to verify that the GPS receiver and navigation processor are properly designed and integrated to produce a satisfactory navigation solution while experiencing predetermined and precisely controlled variations in the RF signal quality and vehicle dynamics.

B.2.2.1. GPS Aided Navigation Performance.

B.2.2.1.1. Test Objective.

The test objective is to verify that the integrated GPS receiver can track GPS signals while being aided by INS data, and that the navigation processor produces a correct navigation solution from available GPS and inertial measurements. The navigation performance will be evaluated under dynamic conditions without jamming.

B.2.2.1.2. Special Test Equipment.

A GPS simulator coupled to an inertial data simulator is required for this test.

B.2.2.1.3. Test Methods.

a. Simulator Configuration – The simulator will initially be configured to provide a nominal constellation with the Test Item remaining in a static condition. A dynamic profile that exercises the Test Item against its intended application should then be started. For additional background information about GPS simulator configuration, see Annex A.
b. Test Execution - The Test Item will be powered on and allowed to navigate for 1 hour or the time to collect a complete almanac and become stabilized. The Test Item will then be powered off and restarted, and allowed to navigate in a simulated environment using a dynamic profile which will exercise it to its application limits.

B.2.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Simulator identification and scenario configuration.
Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc..)
Test Item MIL-STD 1553B and IP data.

Data will be reported in the measurement units of the requirements document. The Test Item navigation solution and time data from the MIL-STD 1553B or instrumentation port (IP) will be compared to the simulated dynamic profile. For all test configurations, the accuracy of the navigation solution will be determined. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers. Position and velocity data will be evaluated against the specified allowable error rates.

B.2.2.2. Satellite Reacquisition.

B.2.2.2.1. Test Objective.

The use of the term “Reacquisition” in this test does not imply any particular acquisition time performance standard. As explained in the GPS Receiver CTP, para 2.2.3, acquisition time parameters have been given different meanings by different GPS programs. The purpose of this test is to verify that the INS-aided GPS receiver can reacquire satellites, reestablish the channel tracking states, and resume accurate navigation within a specified time following a short duration signal loss due to events such as blockage, jamming, and excessive dynamics; and to verify that the navigation processor solution output is consistent with the availability of GPS measurements. This test will simulate the loss of all SVs, an occasional SV loss, and the loss of sufficient SVs to result in an underdetermined navigation solution. The effect of simulated INS aiding during SV reacquisition trials shall also be evaluated.

B.2.2.2.2. Special Test Equipment.

A GPS simulator coupled to an inertial data simulator is required for this test.

B.2.2.2.3. Test Methods.

a. Simulator Configuration – Simulated inertial data inputs synchronized with the dynamic profile utilized by the GPS satellite signal generator shall be applied to the GPS receiver. The simulator will initially be configured to provide a nominal constellation of four satellites in a static position scenario with good Geometric Dilution of Precision (GDOP). The remainder of the test will be conducted under a suitable dynamic scenario. After 5 minutes of navigation, a +100 dB attenuation shall be applied to both frequencies for specified periods of time. Following each attenuation period, the Test Item will be allowed to recover to a normal navigation mode. First, all but three visible SVs will be attenuated for a specified period and re-enabled for two minutes. Then all but two SVs will be attenuated for a specified period and re-enabled, followed by all but one, and finally with all satellite signals attenuated. This cycle shall be repeated (attenuating the same SVs) three times. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution - The Test Item will be initialized and commanded to the navigation mode and allowed to acquire a stable, static navigation solution while processing simulated GPS RF and inertial measurements. The Test Item shall remain in the navigation mode for the remainder of the test.

B.2.2.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The Test Item data shall be analyzed to determine the Test Item’s ability to resume normal navigation after loss of a minimum constellation, and to verify that acceptable navigation solution degradation occurred during the periods of signal outage. SV reacquisition times shall be calculated and compared to system requirements. GPS receiver tracking status data will be examined in order to evaluate the effectiveness of INS aiding.

B.2.2.3. Figure of Merit Accuracy.

B.2.2.3.1. Test Objective.
The purpose of this test is to verify that the navigation processor Figure of Merit (FOM) is calculated as required by the specification, in spite of INS aiding to the navigation processor, and that the Test Item uses appropriate SV selection strategies to maintain a suitable SV tracking configuration.

B.2.2.3.2. Special Test Equipment.
A GPS simulator coupled to an inertial data simulator is required for this test.

B.2.2.3.3. Test Methods.
a. Simulator Configuration – Simulated inertial data inputs synchronized with the dynamic profile utilized by the GPS satellite signal generator shall be applied to the GPS receiver. The simulator will initially be configured to provide a nominal constellation of four satellites in a static position scenario with good GDOP. The remainder of the test will be conducted under a suitable dynamic scenario. SV geometry shall be set to produce a temporary GDOP hole where the GDOP shall be at least 300 for a period of twenty minutes. The poor satellite geometry will result in a GPS navigation solution that slowly degrades with time. The FOM calculations will also be tested by dropping to three satellites for 20 minutes and setting the User Range Accuracy (URA) in the navigation message to a high value. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution - The Test Item shall be initialized and then commanded into the navigation mode in a simulated GPS environment.

B.2.2.3.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The Test Item navigation processor solution will be analyzed to verify navigation accuracy. The navigation error and the FOM will be analyzed to evaluate if the FOM reflects the true error, as required by the specification, for each degraded case tested, and that the navigation error is consistent with the quality of the GPS RF and inertial measurements provided. The analysis shall verify that the FOM reflects the effects of SV geometry when GDOP is very large, when there are fewer than four satellites, and when URA is set high.

B.2.2.4. Multipath Characterization.

B.2.2.4.1. Test Objective.

The purpose of this test is to characterize the accuracy of INS-aided GPS receiver's pseudo-range measurements while subjected to multipath signals, and to ascertain the impact of any measurement errors on the GPS/INS solution output by the navigation processor. The GPS receiver will be subjected to both In-Chip and Out-of-Chip conditions. In-Chip and Out-Of-Chip conditions refer to the offset between the delayed signal and the direct signal in terms of the fundamental clocking period (one chip) of the code. An In-Chip delay is one in which the offset is one chip or less (within one chip) and an Out-Of-Chip delay is one in which the offset is greater than one chip.

B.2.2.4.2. Special Test Equipment.

A GPS simulator coupled to an inertial data simulator is required for this test.

B.2.2.4.3. Test Methods.

a. Simulator Configuration – Simulated inertial data inputs synchronized with the dynamic profile utilized by the GPS satellite signal generator shall be applied to the GPS receiver. The simulator will initially be configured to provide a nominal constellation of four satellites. The first 30 minutes of the test employs a static position scenario with good GDOP. The second 30 minutes of the test involves running one circuit of a dynamic scenario. During this one-hour data collection period, one selected satellite shall have a second, delayed signal (multipath) added to the simulated satellite signals. The multipath shall be switched from In-Chip to Out-Of-Chip every five minutes. Because the boundary between In-Chip and Out-Of-Chip is truly 1.5 chips, this testing should be conducted at a 0.5 chip offset and at a 1.5 chip offset. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution - A pseudo-range offset between the direct and delayed path signals of an SV in the satellite constellation shall be simulated. The Test Item shall be tracking 4 SVs in State 5 at the start of the test.

B.2.2.4.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Pseudo-range measurements will be evaluated with due consideration of anomalies resulting from ionospheric estimations, position errors and relative channel delays. Carrier to Noise Ratio (C/No) and FOM plots will be studied to determine if code tracking errors were due to multipath. Proper tracking of SVs during the test shall also be evaluated. Statistics shall be calculated of the pseudo-range measurement errors during static and dynamic conditions, as a function of GDOP, and during both In-Chip and Out-Of-Chip multipath conditions.

B.2.2.5. INS-Aided Degraded Operating Conditions.

B.2.2.5.1. Test Objective.

The objective of this test is to ensure that the GPS receiver can continue to operate as an effective navigation system under conditions of less that 4 SV visibility through effective use of INS aiding.

B.2.2.5.2. Special Test Equipment.

A GPS simulator coupled to an inertial data simulator is required for this test.

B.2.2.5.3. Test Method.

a. Simulator Configuration – The simulator will initially be configured to provide a nominal constellation with the Test Item remaining in a static condition. A dynamic profile that exercises the Test Item against its intended application should then be started. The INS error model shall be initialized to provide a bounded error growth as required by the system specification for all test cases. Initially, the simulator will provide a constellation of four SVs under unjammed conditions. The number of SVs will then be reduced to 3. Later, the number of SVs will be reduced from three to two. For additional background information about GPS simulator configuration, see Annex A.

b. Test Execution - The Test Item will be initialized and commanded to the navigation mode and allowed to acquire a stable, static navigation solution while processing simulated GPS RF and inertial measurements. The Test Item shall remain in the navigation mode for the remainder of the test. Baro aiding to the navigation solution shall be disabled.

B.2.2.5.4. Data Collection and Analysis Procedures.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.
Jammer settings and times.

Data will be reported in the measurement units of the requirements document. The first objective of the analysis shall be to determine the GPS receiver's ability to maintain smooth and proper navigation solutions during 3-SV conditions. From the onset of 2-SV tracking until the end of the test, it shall verify that the system outputs approach and replicate the INS signals.

B.3. VAN

Two functional tests and one performance test are recommended for van testing of an Integrated GPS/INS. It is recommended that the installation in the van be representative of the ultimate application, including signal levels, vibration, temperature, etc. The Test Manager should ensure that test methods employed in the van tests replicate as closely as possible the flight test methods, to ensure that any observed changes in performance are not induced by the procedures. Testing in a motor vehicle, or "van", provides the least expensive means to simultaneously expose an INS to earth motion, translation, and heading change. In addition, it allows an opportunity to test the integration and installation test package before conducting more expensive flight testing. For these reasons, van testing is recommended before a flight test program begins. Table 7 lists GPS/INS van tests and identifies the test objectives, test, and CTP test description paragraph associated with each test.

Table 7. Van Tests of the Integrated GPS/INS

Test Objective	**Responsible Test**	**CTP Test Paragraph**
Functional Tests		
Demonstrate acceptable:		
Static Navigation	Van GPS/INS Static Navigation	B.3.1.1.
Aided Alignment	Van GPS/INS Aided Alignment	B.3.1.2.
Performance Tests		
Evaluate performance following:		
GPS/INS Performance	Van GPS/INS Navigation	B.3.2.1.

B.3.1. Functional Tests.

B.3.1.1. Van GPS/INS Static Navigation.

B.3.1.1.1. Test Objectives.

The test objectives are to verify that the Test Item is functioning properly as installed in the van and to determine that a correct navigation solution is being generated, displayed, and recorded.

B.3.1.1.2. Special Test Equipment.
None required.

B.3.1.1.3. Test Methods.
The Test Item will be initialized, aligned, and switched to the navigation mode with the van static over a surveyed benchmark. The basic navigation configuration will be tested as well as any special modes that use additional information denoting that the host vehicle is stationary. The Test Item position and velocity data will be recorded. The duration of the test will be at least 15 minutes for each navigation configuration/mode tested.

B.3.1.1.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The Test Item data will be processed and analyzed to verify navigation accuracy and proper functioning as installed.

B.3.1.2. Van GPS/INS Aided Alignment.

B.3.1.2.1. Test Objectives.
The test objective is to evaluate the Test Item's position and velocity accuracy following an alignment aided by its internal GPS. A second test will be conducted to allow the Test Item to conduct a normal start, with both GPS initialization and INS alignment proceeding simultaneously. This test validates the Laboratory Aided Alignment test in the Test Item's field test configuration.

B.3.1.2.2. Special Test Equipment.
None required.

B.3.1.2.3. Test Methods.
The Test Item will be allowed to complete a GPS initialization with the INS subsystem disabled. The INS will be enabled and allowed to complete a GC alignment, and then switched to the navigation mode. Following alignment, the duration of the test will be a function of the expected mission duration of the Test Item, but not less than one Schuler cycle (84.4 minutes). The test will be repeated with the Test Item being allowed to conduct a normal start.

B.3.1.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The position and velocity data from both the integrated system outputs and the INS-only outputs will be evaluated against the specified allowable error rates. The two data sets will be compared to ensure that the INS used the GPS aiding in its alignment.

B.3.2. Performance Evaluation.

B.3.2.1. Van GPS/INS Navigation.

B.3.2.1.1. Test Objective.

The test objective is to evaluate the Test Item position and velocity accuracy, under the dynamic velocity and vibration conditions typical of a van environment, following an aided GC alignment, and also following an in-flight alignment.

B.3.2.1.2. Special Test Equipment.

None required.

B.3.2.1.3. Test Methods.

The test will begin with the van parked over a surveyed benchmark and oriented with either a N/S or E/W heading. The Test Item will be turned on, initialized, and switched to navigation mode with the van static. Following a full accuracy GC alignment, the Test Item will be switched into the navigation mode and the van will depart the surveyed benchmark and proceed along a ground course. The van will return to the initial surveyed benchmark at the end of the circuit. The van will again proceed around the ground course, during which time the INS will be disabled and then commanded to perform an in-flight alignment. Following the alignment, the van will continue on the test course for the remainder of the test period, and return to the initial surveyed benchmark.

B.3.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)

Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. For all test configurations, the accuracy of the Position, Velocity and Time (PVT) solution will be determined. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4. <u>FLIGHT</u>

A suitable truth source, such as a Time-Space-Positioning-Information (TSPI) system or a tracking system, is needed to evaluate flight tests. In addition, the Test Manager must plan for the flight phase with care. If testing is to be done on multiple aircraft types, the test package should not be changed to accommodate installation issues, in order to ensure compatibility of test results. If the installation is to be in an aircraft that is representative of the ultimate application, its installation should replicate that installation as much as possible. However, a test installation also must accommodate a data recording capability not included in an operational installation. In all cases, advance concern must be given to mounting, power availability, antenna placement, wiring, and maintenance access, especially in more compact aircraft such as the “fighter”. Table 8 lists GPS/INS flight tests and identifies the test objectives, test, and CTP test description paragraph associated with each test. These tests are separated into Functional and Performance objectives:

Table 8. Flight Tests of the Integrated GPS/INS

Test Objective	Responsible Test	CPT Test Paragraph
Functional Tests		
Demonstrate acceptable:		
Static Navigation	Flight GPS/INS Static Navigation	B.4.1.1.
Performance Tests		
Evaluate performance following:		
GPS/INS Alignment	Cargo Aircraft GPS/INS GC Alignment	B.4.2.1.
GPS/INS EIA	Cargo Aircraft GPS/INS Enhanced Interrupted Alignment	B.4.2.2.
GPS/INS IFA	Cargo Aircraft INS In Flight Alignment (IFA)	B.4.2.3.
GPS/INS Fighter Performance	Fighter GPS/INS Flight Profiles	B.4.2.4.
GPS/INS IFA	Fighter GPS/INS In Flight Alignment (IFA)	B.4.2.5
GPS/INS Helicopter Performance	Helicopter GPS/INS Flight Profiles	B.4.2.6
GPS/INS IFA	Helicopter GPS/INS In Flight Alignment (IFA)	B.4.2.7

B.4.1. Flight Functional.

B.4.1.1. Flight GPS/INS Static Navigation.

B.4.1.1.1. Test Objectives.
The test objectives are to verify that the Test Item is functioning properly as installed in the aircraft and to determine that the Test Item navigation solution is being generated, displayed, and recorded.

B.4.1.1.2. Special Test Equipment.
None required.

B.4.1.1.3. Test Methods.
The Test Item will be initialized, aligned, and switched to the navigation mode with the aircraft parked on a N/S heading over a surveyed benchmark. The basic navigation configuration will be tested as well as special navigation modes that use additional information that the host vehicle is stationary. The duration of the test will be at least 15 minutes for each navigation configuration/mode tested.

B.4.1.1.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

- Test equipment identification and calibration dates.
- Test Item identification.
- Test Item navigation solution and time output at 1 Hz minimum.
- Test Item health status and state or tracking codes.
- Test Item internal accuracy estimators (FOM, EHE, etc.)
- Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. The data will be reviewed to determine that the Test Item is functioning properly. The Test Item individual subsystem and integrated navigation solutions will be compared with the static surveyed benchmark coordinates to verify the system is operating properly.

B.4.2. Flight Performance.

B.4.2.1. Cargo Aircraft GPS/INS GC Alignment.

B.4.2.1.1. Test Objective.
The test objective is to evaluate Test Item position and velocity accuracy following a GPS-aided gyrocompass (GC) alignment in a cargo aircraft flight environment.

B.4.2.1.2. Special Test Equipment.
None required.

B.4.2.1.3. Test Methods.

Each test will begin over a surveyed benchmark. To induce a maximum error, the Test Item should be aligned with the aircraft 90º from the primary direction of the flight path. After the Test Item has completed acquisition and alignment, and has a stable navigation solution, the aircraft will depart the surveyed benchmark and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

B.4.2.1.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4.2.2. Cargo Aircraft GPS/INS Enhanced Interrupted Alignment.

B.4.2.2.1. Test Objective.

The test objective is to evaluate the Test Item position and velocity accuracy following a GPS-aided enhanced interrupted alignment (EIA) in a cargo aircraft flight environment. This test is needed only if the Test Item does not have a zero-velocity update capability.

B.4.2.2.2. Special Test Equipment.

None required.

B.4.2.2.3. Test Methods.

The vehicle with the Test Item installed shall be oriented in any direction and a GPS-aided GC alignment shall be completed. At the end of the GC alignment, the Test Item shall be switched to the navigation mode and the vehicle shall be taxied to a new heading at least 70º from the initial heading, within 10 minutes. When stopped over a surveyed benchmark, the GPS-aided GC alignment mode will be reentered for a prescribed time period. The vehicle must be completely stopped prior to re-entering GC alignment and remain stopped throughout the duration of the alignment. Following a specified GC alignment period, the aircraft will be switched back to navigation mode, depart and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

B.4.2.2.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Position and velocity data from the INS subsystem, as well as the integrated solution, will be evaluated against the specified allowable error rates.

B.4.2.3. Cargo Aircraft GPS/INS In Flight Alignment (IFA).

B.4.2.3.1. Test Objective.

The test objective is to evaluate the Test Item performance under flight dynamics following a GPS-aided in-flight alignment.

B.4.2.3.2. Special Test Equipment.

None required.

B.4.2.3.3. Test Methods.

Each test will begin over a surveyed benchmark. The inertial subsystem of the Test Item will be disabled and the GPS subsystem will be allowed to acquire a stable navigation solution. The aircraft will depart and proceed along the selected flight profile. The Test Item will be commanded to perform a GPS-aided in-flight alignment. After completion of the flight profile, the aircraft will return to the surveyed benchmark

B.4.2.3.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4.2.4. Fighter GPS/INS Flight Profiles.

B.4.2.4.1. Test Objective.
The test objective is to evaluate the Test Item position and velocity accuracy in a fighter flight environment.

B.4.2.4.2. Special Test Equipment.
None required.

B.4.2.4.3. Test Methods.
For fighter testing, flight profiles should be selected that will subject the Test Item to representative end-application dynamics, or to the limits of the test platform. Each test will begin over a surveyed benchmark. To induce a maximum error, the Test Item should be aligned with the aircraft 90° from the primary direction of the flight path. After the Test Item has completed acquisition and normal alignment, and has a stable navigation solution, the aircraft will depart the surveyed benchmark and proceed along the selected flight profile. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

B.4.2.4.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and individual subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4.2.5. Fighter Aircraft GPS/INS In Flight Alignment.

B.4.2.5.1. Test Objective.
The test objective is to evaluate the Test Item performance under fighter flight dynamics following an in-flight alignment.

B.4.2.5.2. Special Test Equipment.
None required.

B.4.2.5.3. Test Methods.
The INS portion of the Test Item will be disabled and the GPS portion will be allowed to acquire a stable navigation solution. The aircraft will depart and proceed along the selected flight profile. The Test Item will be commanded to perform an in-flight alignment. After the IFA is complete, the Test Item will be switched into aided navigation. After completion of the flight profile, the aircraft will return to the surveyed benchmark. The Test Item will be baro-aided for the duration of the flight.

B.4.2.5.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and individual subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4.2.6. Helicopter GPS/INS Flight Profiles.

B.4.2.6.1. Test Objective.
The test objective is to evaluate the Test Item's position and velocity accuracy in a helicopter flight environment.

B.4.2.6.2. Special Test Equipment.
None required.

B.4.2.6.3. Test Methods.
For helicopter testing, flight profiles should be selected that will subject the Test Item to representative end-application dynamics, or to the limits of the test platform. Each test will begin over a surveyed benchmark. Following Test Item acquisition and alignment, the helicopter will depart the surveyed benchmark and proceed along the selected flight profile. The test item will be baro-aided for the duration of the flight. The helicopter will return to the surveyed benchmark at the end of each test.

B.4.2.6.4. Data Collection and Analysis Methods.
As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.

Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and individual subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

B.4.2.7. Helicopter GPS/INS In Flight Alignment.

B.4.2.7.1. Test Objective.

The test objective is to evaluate the Test Item performance under helicopter flight dynamics following an in-flight alignment.

B.4.2.7.2. Special Test Equipment.

None required.

B.4.2.7.3. Test Methods.

The inertial portion of the Test Item will be disabled and the GPS portion will be allowed to acquire a stable navigation solution. The aircraft will depart and proceed along the selected flight profile. The Test Item will be commanded to perform an in-flight alignment. The Test Item will be baro-aided for the duration of the flight. The aircraft will return to the surveyed benchmark at the end of each test.

B.4.2.7.4. Data Collection and Analysis Methods.

As a minimum, test relevant data will be collected and recorded as follows:

Test equipment identification and calibration dates.
Test Item identification.
Test Item navigation solution and time output at 1 Hz minimum.
Test Item health status and state or tracking codes.
Test Item internal accuracy estimators (FOM, EHE, etc.)
Test Item 1553 and IP data.

Data will be reported in the measurement units of the requirements document. Integrated navigation data and subsystem navigation data will be evaluated for specification compliance. Particular emphasis will be placed on analyzing Test Item operation in turns, during constellation changes, and during maneuvers.

ANNEX A TO
GLOBAL POSITIONING SYSTEM/
INERTIAL NAVIGATION SYSTEM

CORE TEST PLAN

Test Item Accuracy Determination
Using A GPS Simulator

ACRONYMS

CTP	Core Test Plan
DC	Direct Current
DOP	Dilution Of Position
ECEF	Earth Centered Earth Fixed
GPS	Global Positioning System
LENU	Local East North Up
SA/A-S	Selective Availability/Anti-Spoof
SSCWG	Satellite Simulator Control Working Group
PC	Personal Computer
PVT	Position, Velocity, and Time
UTC	Universal Time Constant
WGS	World Geodetic System
Vdc	Volts direct current

Test Item Accuracy Determination Using a GPS Simulator

This Annex results from input from the GPS Satellite Simulator Control Working Group (SSCWG) and supplements the GPS Receiver Core Test Plan (CTP). It details the items to be **<u>considered</u>** when conducting simulator testing of a GPS receiver. Many variables can affect the accuracy performance of a GPS receiver while it's navigating using the signals provided by a GPS simulator. To get consistent, repeatable test results from different test agencies, and even within a single agency, the test community must establish common simulator set-up and test procedures. Common simulation variables such as start position, start time, dynamic profile definition, ephemeris and almanac parameters, satellite clock terms, and atmospheric delay (ionosphere and troposphere) modeling can all impact the performance of the GPS system under test.

1. <u>SCOPE</u>

1.1. Purpose.

The purpose of this Annex is to establish common procedures and GPS simulator set-up parameters that can be used to determine the accuracy of a GPS receiver. The procedures herein are for guidance only, and are only applicable for accuracy testing. These standard GPS simulator set-up configurations and test methods should lead to repeatable test results.

1.2. Limitations.

The procedures and methods described below apply to testing a wide variety of GPS receiver systems using a typical GPS simulator, but may not apply to unique integrations and/or applications. The procedures are used as guidelines to assist in establishing consistency of testing. It should also be noted that the systems under test are not actually in motion. Thus, the simulated GPS signal environment is the only aspect being considered.

Since several GPS simulator manufacturers exist and each may have a different user interface, the specific procedures for the configuration of each unique simulator will not be addressed. Rather, general set-up guidelines that could be applied to each unique system are discussed.

1.3. Disclaimer.

The use of trade names in this Annex does not constitute an official endorsement or approval of the use of such commercial hardware or software. This Annex may not be cited for purposes of advertisement.

2. FACILITIES AND INSTRUMENTATION

2.1. Facilities.

The facility must contain a laboratory test area that has sufficient security measures to house the GPS simulator as well as military GPS receivers. The facility should also provide conditioned external power sources and back-up power to reduce test interruption in the event of short-term power outages.

2.2. Instrumentation.

As shown in Figure 1, the basic test configuration consists of a GPS Simulator, the GPS receiver under test, a data collection system (normally a PC/buffer box) and data analysis tools.

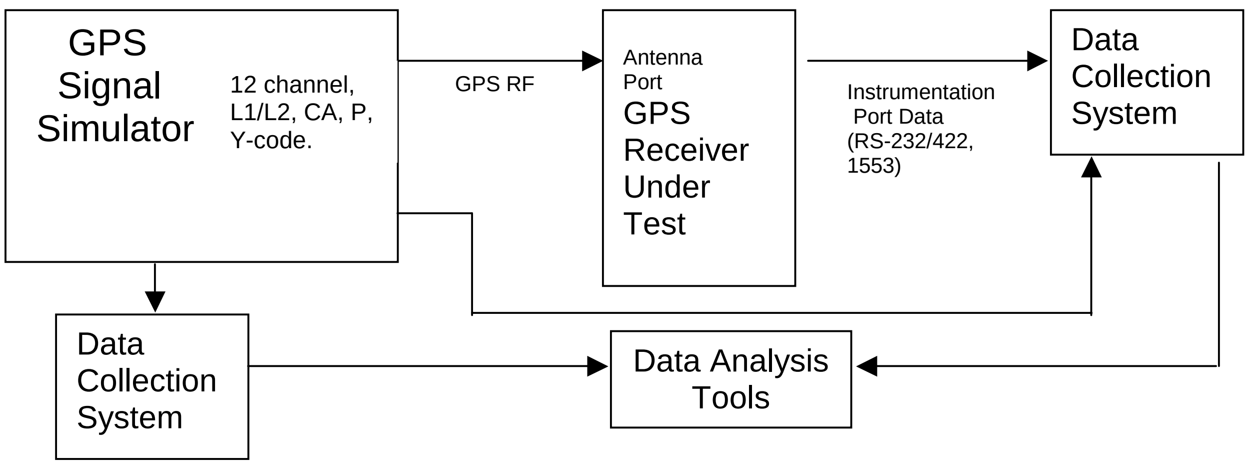


Figure 1. Basic Test Configuration

2.2.1. GPS Simulator.

The GPS Simulator is used to provide the required GPS signals to the GPS receiver under test. Most modern GPS simulators are capable of simulating the signals of up to 12 complete GPS satellites at one time. 12-channel coverage is not required, but recommended to allow "all-in-view" simulations. Selective Availability and Anti-spoofing (SA/A-S) capabilities are required for testing military GPS receivers and this option is available for many GPS simulators. The truth data (typically ECEF position, velocity, and time) is normally recorded from the simulator to allow comparison with the navigation solution of the GPS receiver under test. This data may be recorded internally within the simulator or externally using a PC, depending on the GPS simulator's architecture.

2.2.2. GPS Simulator-to-GPS Receiver interface.

The simulated GPS signal is injected into the antenna port of the GPS receiver under test. It is important to establish the proper input signal level at the antenna port of the GPS receiver. There are a variety of antenna/pre-amplifier configurations used on GPS systems and being familiar with the configuration before testing is required. A non-amplified antenna system will normally accept input GPS signals at nominal, live levels directly at the antenna port. On the other hand, if an amplified antenna system (which requires a DC voltage provided to the antenna) is incorporated, a simple “matching” network may be required. This will simulate the remote antennas electrical characteristics and allow the GPS receiver to accept the simulated GPS signals. Figure 2 shows the basic network required to inject the simulated GPS signal into a GPS receiver that normally uses an external amplified antenna.

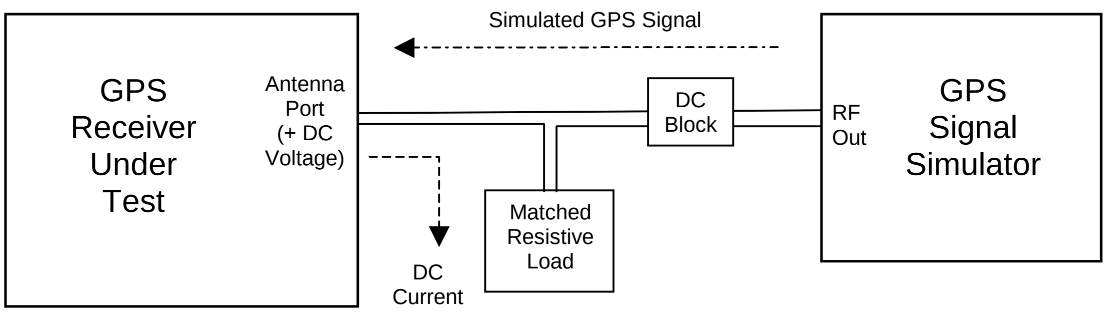


Figure 2. GPS Receiver antenna matching set-up.

As shown in Figure 2, the dc current that is normally consumed by the remote antenna is presented to the resistive load to simulate the antenna. Care must be taken to properly match the receiver’s antenna port dc output voltage and the resistive load to establish the proper current flow from the antenna port. If a significant mismatch occurs the receiver may indicate an external antenna fault and will not track properly. Simple measurement of the voltage (normally from 5-15 Vdc) and current with an external antenna connected can preclude mismatch problems.

Once the proper matching is accomplished, the gain of the amplified antenna must be known to achieve nominal signal levels at the GPS receiver’s antenna port. Compensation of the antenna gain is achieved by increasing the output signal level of the simulator to compensate for the lack of amplification. Additionally, any cable losses due to the length of coaxial cable between the GPS simulator and receiver under test should be characterized and proper compensation applied.

2.2.3. Instrumentation Port

Most GPS receivers have an instrumentation port that provides the navigation solution (position, velocity, and time (PVT)) over an RS-232/422 serial interface. Other interfaces that may be present are MIL-STD-1553 or ARINC 429. The PVT data from the GPS receiver is recorded and compared (using data analysis tools) to the PVT data generated from the GPS simulator (truth) to determine the accuracy of the GPS receiver. The method of recording this data is receiver specific and may contain additional information, based on test requirements.

3. TEST CONDITIONS

3.1. GPS Simulator set-up parameters.

There are many simulator set-up considerations that should be addressed prior to executing this accuracy test. These are:

- Simulation Start Date and Time.
- Simulation Position.
- Ephemeris and Almanac.
- Satellite Clock Terms.
- GPS – UTC Time Translation Parameters.
- Atmospheric Delay Modeling.

In most cases, the GPS simulator will insert default values into these parameters. Default values are not likely to corrupt a unique test conducted with a particular simulator, but if the test is repeated using a different simulator, the default values used may be different. This would likely affect the resultant accuracy of the GPS receiver under test, thus yielding different results. It is important to consider and verify that these parameters are held constant among tests to get the most repeatable and comparable results.

3.1.1. Start Date/Time and Position

The scenario start date and time and start position (including elevation) are typically user entered and can significantly affect the performance of the GPS system under test due to varying satellite coverage. In many cases, the simulation start times and position are chosen to yield specific coverage and visibility of certain satellites especially if the intention is to characterize the receiver's ability to perform in less than optimum conditions. The simulation start time is normally referenced to a GPS week for which the simulation will apply and must match the applicability date of the ephemeris data. The position is entered similarly and can normally be entered in a variety of formats including Lat/Long or earth-centered earth-fixed (ECEF). Using a standard simulation start time and position (along with ephemeris data described below) will ensure that the GPS receiver under test is exposed to common satellite visibility conditions.

3.1.2. Ephemeris and Almanac Parameters.

The ephemeris parameters describe each satellite's orbit and include correction terms to account for perturbations of the orbit. The GPS simulator will produce ephemeris data as part of the navigation message (sub frames 2 & 3) transmitted for each satellite. Since these data predict current satellite position, it is important that this information is consistent between tests. Most GPS simulators will generate an applicable set of ephemeris parameters based on a default or "canned" ephemeris starting point. These values will be propagated to the user indicated date and time of the scenario. Since not all GPS simulator vendors use the same canned ephemeris values, large differences may exist in the satellite coverage and availability for a given date/time. Changing certain parameters in the ephemeris results in different satellite visibility and coverage, which will affect the Dilution of Precision (DOP) at any given time during the scenario. The DOP is basically the geometric contribution to position error for a given location and time. An example of a set of ephemeris parameters for one satellite is shown below:

**** Week 0893 ephemeris for SV- 5 ************		
ID:	5	
Eccentricity:	1.952426275E-03	e
Time of Applicability(s):	3.599840000E+05	TOE
Orbital Inclination(rad):	9.372728454E-01	I_0
Rate of Right Ascen(r/s):	-8.286059664E-09	OMEGA_DOT
SQRT(A) (m^1/2):	5.153781679E+03	SQRT_A
Right Ascen at TOA(rad):	1.942633791E+00	OMEGA_0
Argument of Perigee(rad):	1.954183053E-01	OMEGA
Mean Anom(rad):	-2.795994470E+00	M_0
mean motion diff(r/s):	5.000565576E-09	DELTA_N
Rate of inclin (r/s):	2.442958970E-10	I_DOT
lat cosine ampl (r):	-9.313225746E-09	CUC
Lat sine ampl (r):	8.447095752E-06	CUS
radius cos ampl (m):	2.044375000E+02	CRC
radius sin ampl (m):	4.643750000E+01	CRS
inclin cos ampl(r):	-3.725290298E-09	CIC
inclin sin ampl(r):	-9.313225746E-09	CIS
week:	0893	
t_gd:	-4.190951586E-09	T_GD
t_oc:	3.599840000E+05	T_OC
Af0(s):	2.359435894E-04	af0
Af1(s/s):	1.932676241E-12	af1
Af2(s/s/s):	0.000000000E+00	af2

It is recommended that a characterized, common set of ephemeris parameters be input into the simulator prior to the beginning of the test to minimize the potential adverse effects. Current and historic almanacs are available for download at https://www.gpstestcoe.com.

The Almanac parameters included in the navigation message (subframe 4) are fewer and less accurate than the ephemeris parameters. When transmitted from the satellite, this information is primarily used for satellite selection and aids the receiver in initial acquisition. An example of a set of almanac parameters for one satellite is shown below:

**** Week 0893 almanac for PRN-01 ***********	
ID:	01
Health: 000	
Eccentricity:	4.933834076E-003
Time of Applicability(s):	61440.0000
Orbital Inclination(rad):	9.615267216E-001
Rate of Right Ascen(r/s):	-8.046049436E-009
SQRT(A) (m^1/2):	5153.618652
Right Ascen at TOA(rad):	2.192091128E+000
Argument of Perigee(rad):	-1.729656591E+000
Mean Anom(rad):	-8.394949546E-003
Af0(s):	1.430511475E-004
Af1(s/s):	0.000000000E+000
week:	0893

Typically, GPS simulator systems allow for operator entry of specific almanac or ephemeris data to be used by the scenario. Manipulating the almanac and ephemeris data conditions can induce less than optimal satellite coverage. Therefore, it is important to use a representative set of initial ephemeris data. Often times, these data can be downloaded from a GPS receiver tracking live satellites or taken from various GPS information sites such as http://www.gpstestcoe.com. It is important to use a consistent set of ephemeris and/or almanac parameters to ensure repeatable test conditions.

3.1.3. Satellite Clock Error Terms.

The GPS simulator will produce satellite clock correction values as part of the navigation message (subframe 1) transmitted for each satellite. In the live environment these values are determined by the Master Control Station and transmitted to the satellite for re-broadcast in the navigation message. These correction parameters are as follows:

- Clock bias (af0)
- Clock drift (af1)
- Frequency drift (af2)
- Clock data ref time (toc)
- Current time epoch (t)
- Correction due to relativistic effects (tr)

Many GPS simulators offer the ability to modify these terms via a separate menu. The primary concern is that consistency is maintained when generating scenarios with respect to the clock correction term values. During the scenario definition these values should be checked for consistency.

3.1.4. GPS - UTC Time Translation Parameters

Since GPS time is based on an atomic clock that is continuously transmitted from the satellite without the leap seconds associated with UTC time, correction parameters must be provided to allow the GPS receiver to convert GPS time to UTC time. These parameters are contained in the navigation message (subframe 4) produced by the simulator and are normally user-entered at a menu. The GPS-UTC translation parameters are as follows:

- Constant Term in Polynomial (Ao)
- First Order term in Polynomial (A1)
- Delta time due to leap seconds.
- Reference time for UTC data.
- UTC Reference week number.
- Reference Week number for future leap seconds.
- Day number.
- Delta Time due to Future Leap Seconds.

Since these parameters include such values as the number of leap seconds and when in time they will apply, it is important to ensure these parameters are consistent between GPS simulations to achieve common time reporting.

3.1.5. Atmospheric delay modeling (Ionospheric and Tropospheric).

GPS receivers may employ Ionospheric and/or Tropospheric Delay Models to correct for the effect of signal delays on the signal-in-space while it is passing through the earth's atmosphere. GPS simulators employ these same various Ionospheric and Tropospheric Delay Models to create this effect on their simulated signals. In many cases, there are a variety of models that can be selected from the simulator's control menu. Below are some common examples of these models:

Ionospheric Delay Models	Tropospheric Delay Models
- Single frequency model	- Collins Phase III
- Uniform Density Shell model	- Collins Phase II
- Klobuchar model	
-Constant Rate Model	

Since the signal delays can be significant (especially for satellites at low elevation angles), it is important to know which model(s) are used in the receiver being tested, and to know that if the model(s) selected for use in the simulator is the same, receiver performance may be enhanced. If testing is to be conducted on multiple simulators, a common choice of models should be employed.

Ionospheric delay parameters are transmitted within the navigation message (subframe 4) to be used by the receiver in the modeling process.

3.1.6. Stationary profile.

The stationary profile simulates a GPS receiver at rest. The simulated GPS constellation progresses through its normal dynamics (rising and setting satellites), while the user platform does not move.

3.1.7. Dynamic Profiles.

The operator can define the desired dynamic profile for a GPS receiver in motion. There are normally two primary methods of establishing profiles within the simulator, a built in trajectory generator and an external trajectory generator.

Built in trajectory generator: Most GPS simulators contain a resident “user motion generator” which allows the user to define the scenario based on a series of high level commands. These commands are typically based on event timing and will contain maneuvers like “*at t=10 sec, change speed to*:”, “*change heading to*:”. These built in commands eliminate the need for the operator to precisely control each maneuver, and the simulator resolves any discontinuities between maneuvers. This method has the drawback that the system “fits” the maneuvers together so it is rare to achieve the *exact* same dynamic profile when dealing with different GPS simulator system vendors. This may make it difficult to compare GPS receiver performance results when tested on different simulators. The advantage of the built in system is that the profiles are usually easy to create. The dynamic profile described in Figure 1, *Standard Yuma Proving Ground Simulated Racetrack Profile*, and Table 2, *Trajectory Profile*, of the GPS CTP is an example of this type of trajectory.

External trajectory generator: This is an option that many GPS simulators include, which allows the dynamic scenario to be provided from an external source such as recorded PVT from actual field test data or data processed elsewhere. Most simulators specify the format of this data and it can often be provided as an ASCII file updated at a 10 Hz rate. The north and east motion of these trajectory profiles are often defined by 7^{th} order polynomials in time to produce very realistic dynamics. By updating the trajectory at a 10 Hz rate and precisely defining the position (and time derivatives - velocity and acceleration) at each update, the trajectory is consistent between maneuvers. This allows very good repeatability when a common trajectory is used on different GPS simulators since the “ambiguity” between maneuvers is removed.

3.2. Scenario Definition.

To assist in establishing a common scenario profile, the parameters described in sections 3.2.1 through 3.2.4 below and the associated data files can be used. It is important that the specified profile, almanac data, UTC, and atmospheric parameters are used to help ensure consistency. The following basic scenario set-up parameters are used:

Start Time: 00:00 (UTC time)
Start Date: 2/23/97
Start Position: N 33° 0.0’ 0.0’’, W 117° 0.0’ 0.0”, 0 m (datum altitude)
Start Heading: 0º
Start Velocity: 0

3.2.1. Vehicle Profile.

The profile combines periods of dynamics and stationary conditions. The three hour and 45 minute scenario is partitioned into static and dynamic periods as follows:

A. 0:00 - 1:15 static
B. 1:15 - 1:45 dynamic
C. 1:45 - 2:15 static

D. 2:15 - 2:45 dynamic
E. 2:45 - 3:15 static

The dynamic portions of the profile consist of a five-minute loop repeated six times during each dynamic portion of the scenario. The five-minute loop begins and ends with the vehicle stationary (approximately). The motion is defined in a Local East-North-Up (LENU) coordinate system centered at 33 degrees north latitude and 117 degrees west longitude, on the WGS-84 ellipsoid. The motion is determined by two seventh degree polynomials, one giving position in meters as a function of time in the east axis, the other in the north axis. These polynomials are defined as follows:

$$\mathrm{East}(t) = e_0 + e_1*t + e_2*t^2 + e_3*t^3 + e_4*t^4 + e_5*t^5 + e_6*t^6 + e_7*t^7$$
$$\mathrm{North}(t) = n_0 + n_1*t + n_2*t^2 + n_3*t^3 + n_4*t^4 + n_5*t^5 + n_6*t^6 + n_7*t^7$$

where,

$e_0 = -4.292947051050665*10^{-10}$
$e_1 = 1.839701209939923*10^{-3}$
$e_2 = -2.763153154769556*10^{-2}$
$e_3 = 9.252664448126804*10^{-2}$
$e_4 = -1.809709623386738*10^{-3}$
$e_5 = 1.194081434297117*10^{-5}$
$e_6 = -3.297237534656104*10^{-8}$
$e_7 = 3.28468111961149*10^{-11}$

$n_0 = -1.054859403517086*10^{-8}$
$n_1 = 7.133599794465932*10^{-3}$
$n_2 = -1.07121079362214*10^{-1}$
$n_3 = 3.584565790906435*10^{-1}$
$n_4 = -5.956432046984027*10^{-3}$
$n_5 = 3.571083860640097*10^{-5}$
$n_6 = -9.256309728667498*10^{-8}$
$n_7 = 8.815533063839785*10^{-11}$

For convenience in implementation on simulators, the LENU and ECEF position, velocity, acceleration and jerk have been calculated for each integral second and stored as files in both Excel format and ASCII:

trj_lenu.xls - Excel format, LENU at N33, W117, on the WGS-84 ellipsoid
trj_ecef.xls - Excel format, WGS-84 ECEF rectangular coordinates
trj_lenu.txt - Text ASCII, LENU at N33, W117, on the WGS-84 ellipsoid
trj_ecef.txt - Text ASCII, WGS-84 ECEF rectangular coordinates

Note, the end of one loop and the beginning of the next contains a slight discontinuity that could cause the receiver to break lock. To eliminate the discontinuity, the last second of the loop has been modified from the polynomials given above. The change provides a constant velocity from the end of the loop, to the end of the first second in the next loop. The Excel and text files listed above contain the necessary data values. In using the Excel or text files to produce the trajectory for an entire dynamic interval it should be noted that the last point (point 300), becomes the first point (point 0) for the next loop. Thus point 0 for the second and subsequent loops is redundant and should not be used.

3.2.2. Almanac data.

Utilize the attached almanac (*almanac.alm*) data file to provide the GPS simulator with the appropriate almanac information. This is a broadcast almanac transmitted by one of the live satellites during the first few hours of June 15, 1997, with the week number changed to 894. If the simulator to be used accepts the input of complete ephemeris data, the associated ephemeris file *ephem3.sim* can be used.

3.2.3. UTC parameters.

Ensure that the following UTC parameters are used at the GPS Simulator.

A0(s):	0.00000000000e+00
A1(s/s):	0.00000000000e+00
DeltatLS(s):	11
tot(s):	147456
WNt(weeks):	0
WNlsf(weeks):	144
DN(days):	2
deltatlsf(s):	12

3.2.4. Atmospheric Delay Parameters (Iono and Tropo).

The single frequency ionosphere model is employed with the following parameters:

a0(s):	5.58793544769e-09
a1(s/semi-circle):	1.49011611938e-08
a2(s/semi-circle^2):	-5.96046447754e-08
a3(s/semi-circle^3):	-1.19209289551e-07
b0(s):	8.39680000000e+04
b1(s/semi-circle):	9.83040000000e+04
b2(s/semi-circle^2):	-6.55360000000e+04
b3(s/semi-circle^3):	-5.24288000000e+05

The Collins phase III (or similar) troposphere model is employed using the following parameters:

Zenith Delay:	0m
Scale Height:	10m

Note: A 10-degree satellite visibility mask is established for this scenario to minimize the effects of differing tropospheric modeling implementation.

4. TEST PROCEDURES

The following general test procedures can be used to establish a scenario, conduct the test, and review the data for a standard GPS simulation.

4.1. System Configuration.

{See GPS Receiver CTP Addendum (Distribution C)}

a. Configure the GPS simulator as described in Section 3.2 (Scenario Definition) as closely as possible to the recommended parameters. Any deviations should be noted.
b. Determine the nature of the external antenna port of the GPS receiver as described in section 2.2.2 (GPS Simulator to GPS Receiver Interface) and attach the appropriate matching load between the GPS receiver and simulator.
c. Configure the GPS receiver data collection system to record the navigation solution of the GPS receiver under test. At a minimum, collect GPS time, current position, and velocity data at a 1 Hz rate.
d. Reserved.
e. Reserved.

4.2. Test Conduct.

a. Initiate the scenario at the GPS simulator.
b. Place the GPS receiver in the Navigation (or normal tracking) mode and verify that the unit is tracking the GPS simulator signals at nominal levels.
c. Start the data collection system to record the output of the GPS receiver and the GPS simulator truth data. This should run throughout the duration of the scenario. Record the start times in a test log as well as any associated file names for future reference.
d. Allow the receiver to track satellites until it is has a complete almanac (normally about 13 minutes). During this period, confirm normal operation of both the GPS simulator and receiver.
e. Allow the GPS receiver to operate through the duration of the scenario noting any anomalous behavior of the GPS receiver or simulator.

4.3. Data Analysis.

a. At the conclusion of the scenario, harvest the simulator truth data and the GPS receiver output data from the respective data collection systems.
b. Align the two data files based on GPS time from each file.
c. Simple differencing of position, velocities, and other collected parameters will yield the errors of the associated parameters. Often

commercial software such as Excel is adequate. An example of a position error plot is shown in Figure 3.

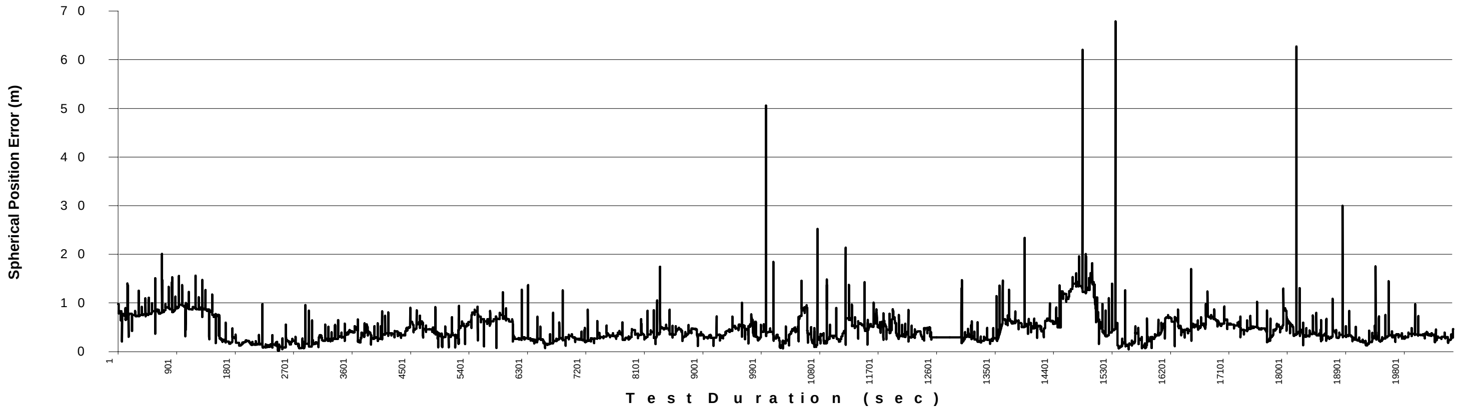


Figure 3. Example of position error plot.

d. Once the differences are determined, a representative plot can be generated. These differences can be statistically analyzed to determine specification compliance of the particular GPS receiver being tested.

e. More elaborate, automated data analysis can be utilized based on the test requirements and the exact tools to be used or developed should be considered early during test preparation.

ANNEX B TO
GLOBAL POSITIONING SYSTEM/
INERTIAL NAVIGATION SYSTEM

CORE TEST PLAN

Tutorial on Means, Sigmas, Confidence Intervals and Tests

Tutorial on Means, Sigmas, Confidence Intervals and Tests

Introduction.

The number of tests necessary to verify system performance has become a significant issue relating to cost and schedule. Previous methods used a confidence limit relating to a specific performance parameter, which is not applicable for all systems. Statistically, the number of tests by evaluating system performance can be estimated or quantified.

Mean and Sigma

For a test event consisting of:

j = 1 to J tests conducted, during which
i = 2 to I data points are collected per test, and
n = IJ, the total number of data points (I being the same for each of J tests, for mathematical simplicity)

Where:

μ_j and σ_j^2 = the mean and variance of the jth test

$\overline{\mu}$ = average of all the μ_j with a variance σ_μ^2

$\overline{\sigma^2}$ = simple average of the J variances σ_j^2

It can be shown(Appendix A) that:

$$\sigma_n^2 = \sigma_\mu^2 + \overline{\sigma^2} \qquad \textit{Equation 1}$$

where

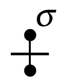
σ^2 variances associated with performance parameters
μ derived from data from a series of tests with
a. $i = 2$ to I data points per test
b. $j = 1$ to J tests
c. $n = IJ$ the total number of data points
(I is the same for each of J tests for mathematical simplicity)

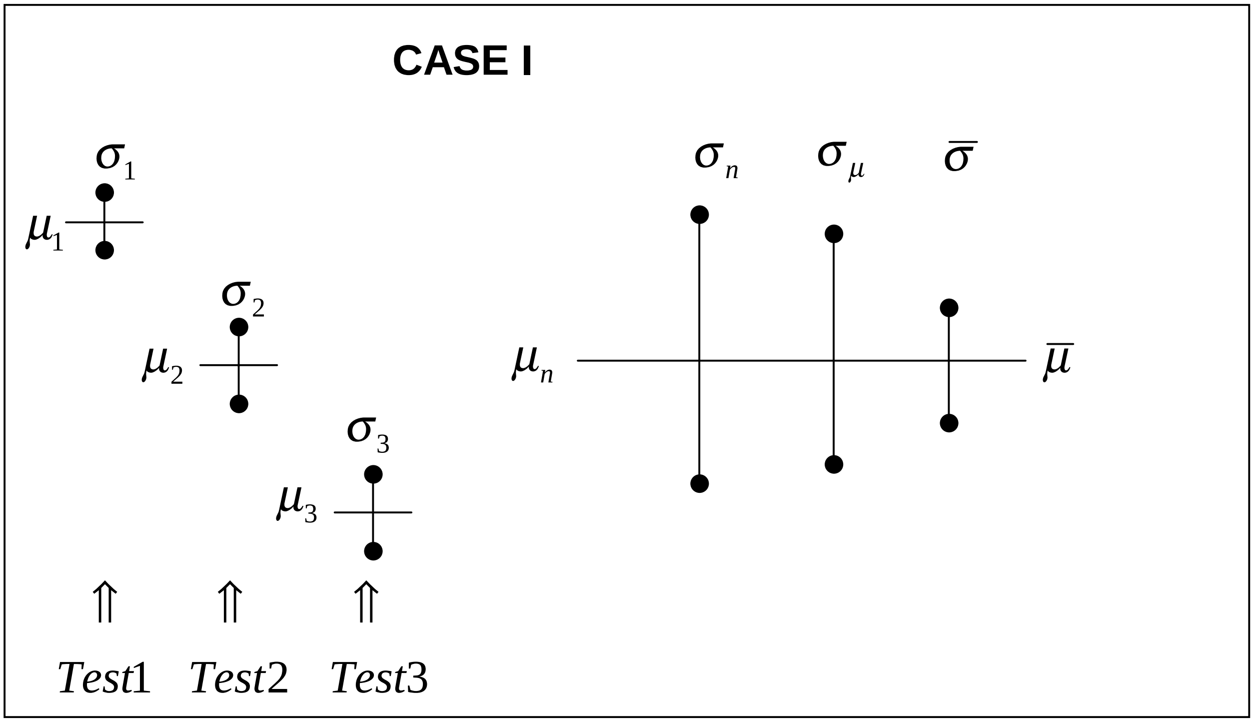
n data points produce a single mean μ_n and variance σ_n^2

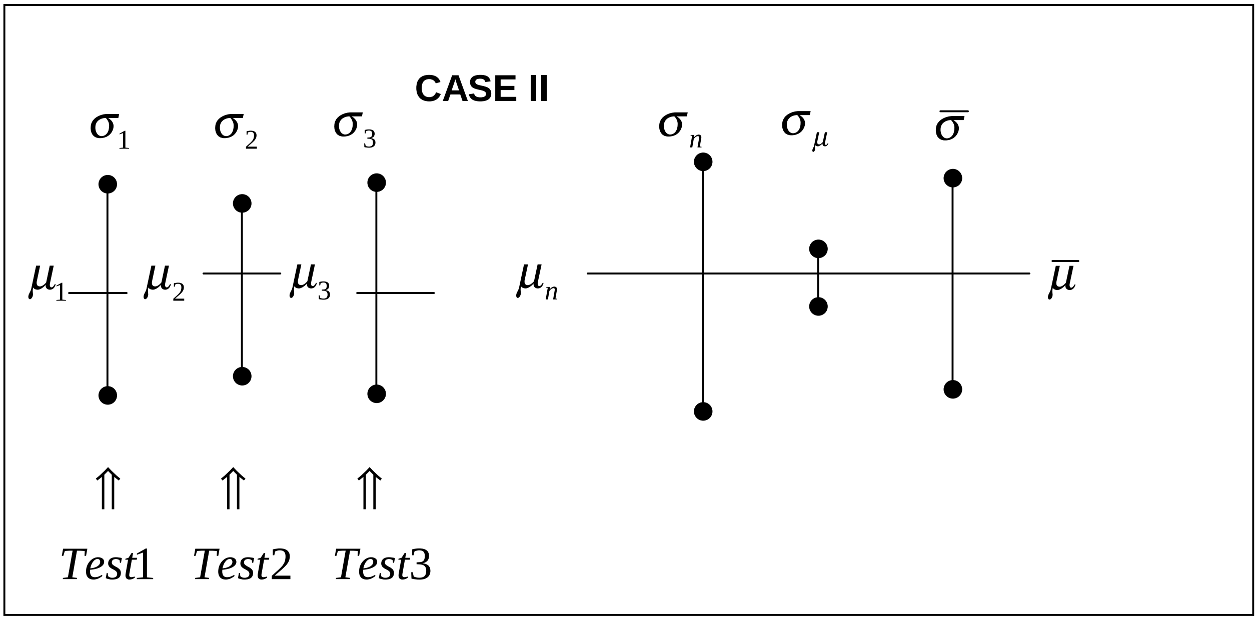
J^{th} test data produce a single mean μ_j and variance σ_j^2

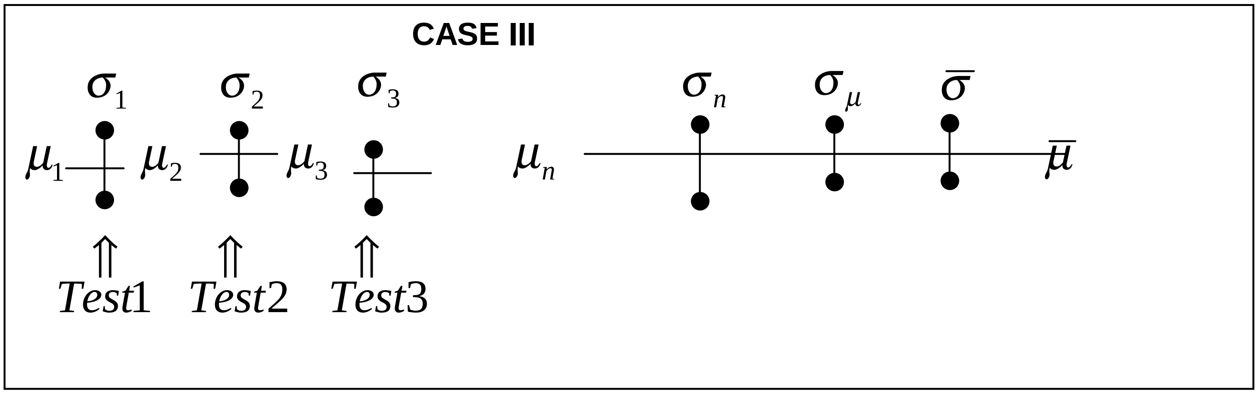
$\bar{\mu}$ average of all the μ_j with a variance σ_μ^2

$\overline{\sigma^2}$ simple average of the J variances σ_j^2

The above is pictorially represented by using the glyp μ  to denote a mean μ bounded by plus and minus sigma (square root of a variance). For notational simplicity, $\sigma_n, \sigma_\mu, \bar{\sigma}$ is used to denote the square root of $\sigma_n^2, \sigma_\mu^2, \overline{\sigma^2}$ with the following Cases developed to illustrate possible test combinations.







In Case I, three tests provided widely different results μ_j, with small variances σ_j^2 for each test, meaning that the test item was very well behaved during each test but changed from test to test: producing the characteristics of large σ_μ^2 and small $\overline{\sigma^2}$.

In Case II, three tests provided nearly identical results μ_j, with very large variances σ_j^2, meaning that the test item was noisy at all times but was telling the same story from test to test: producing the characteristics of small σ_μ^2 and large $\overline{\sigma^2}$.

In Case III, three tests provided similar results μ_j, with small variances σ_j^2, meaning that the test item was well behaved not only during each test but across the test series: producing the characteristics of equivalent σ_μ^2 and $\overline{\sigma^2}$.

From Equation 1, σ_n^2 becomes large with either large σ_μ^2 or $\overline{\sigma^2}$ and therefore by itself provides no insight into during-test or test-to-test test item behavior. Although perhaps not intuitively obvious to the most casual observer, the above is basically a restatement of the Central Limit Theorem.

Confidence Intervals

The cases can be used to illustrate the complexity of assigning confidence levels to test item performance.

Rule: Confidence intervals can <u>always</u> be computed, providing that two or more samples exist. Confidence intervals are defined in terms of the data average $\overline{X}$ and the associated standard deviation S. In general form:

$$\mu = \overline{X} \pm W\sqrt{\frac{S^2}{n}} \qquad \textit{Equation 2}$$

where, as the number of samples n becomes large, $\overline{X}$ approaches the true mean μ and S^2 approaches the true variance σ^2. W is a statistic (a number) dependent both on the confidence level desired (e.g., 95%, so you can say, "I am 95% confident that μ is within $\overline{X} \pm W\sqrt{S^2/n}$ ") and on the number of data samples n used to compute $\overline{X}$ and S. For large $n(\geq 30)$, W is known as the *z statistics* and at the 95% confidence level, W approaches 1.960, meaning that $\pm 1.960\,\sigma/\sqrt{n}$ contains 95% of the whole data population under a bell-shaped distribution curve – that's why we say " 2 sigma is about a 95% confidence level "(because 2 is about the same as 1.960). For small n (2 to about 30), W is known as the *t statistic*: the Student *t* test. For $n = 2$, $W = 12.706$, far larger than 1.960, so you are at best confident that the very large span, $\pm 12.706\sigma/\sqrt{2}$ contains 95% of the population (i.e, you don't know much).

For Case I, if you are in the middle of Test 1, and Test 1 contains many data points $(I > 30)$, you can be 95% confident that the next, $I + 1th$, data point would be within about $\mu_1 \pm 2\sqrt{\sigma_1^2/I}$. However, that doesn't tell you a thing about the expectations for Test 2 and 3. Tests 2 and 3 do tell you that a fourth test should have a mean within about $\overline{\mu} \pm W\sqrt{\sigma_\mu^2/J}$ (where $W = 3.182$ for $J = 4$ tests). Certainly, the factor $3.182/\sqrt{4} > 1.960/\sqrt{30}$ (your knowledge of the location of μ has decreased fourfold now that you are taking test-to-test variations into consideration, even if by coincidence σ_μ^2 were to equal σ_1^2).

For Case II, the large σ_j^2 guarantee that the 95% confidence interval is large during any test j, and the remaining tests do nothing to dispel your lack of confidence because, don't forget, variance are uncertainties in μ.

For both Cases I and II, lots more data is needed to close the desired confidence interval.

For Case III, Tests 2 and 3 define a small confidence interval: it would be statistically difficult to expect a Test 4 to produce significantly different results.

The variances in Equation 1 gain meaning for both Cases I and II. σ_n^2 is large and more data is called for (more tests in the instance of Case I, more date per test in the instance of Case II). For Case III, σ_n^2 is small and – statistically – more data per test or more tests are not called for; this would indicate that the next hierarchy of testing, namely testing K different test items (if available), is ready to be embarked on. Thus, the magnitude of σ_n^2 indicates a correlation with the need for more data, but σ_μ^2 and

$\overline{\sigma^2}$ tell you where the " more data" is required; and they are the variances which should be looked at for a proper balance of I , J , and K in generating "confidence".

The word "statistically" is underlined above for two reasons: (1) usually, we have one test item available $(K=1)$, so we can only infer population performance, and (2) Mother Nature does what she wants, not what we want; the next data point $I+1$ or the next test $J+1$ or the next test item $K+1$ could produce totally different results.

How do we resolve this? Certainly not through statistics alone, which are attuned to Mother Nature only through generalized assumptions which may only peripherally relate to the physics of test items. The question can be statistically addressed through assumptions and guesses about independence of the $i\text{th}$ data point on the $i-1\text{th}$, of the $j\text{th}$ test on the $j-1\text{th}$, and the $k\text{th}$ test item on the $k-1\text{th}$. There exist rigorous methods to accommodate this but very quickly the assumptions and guesses compound to produce mostly speculation, and speculation gets us into trouble. The answer, incontrovertibly, is data and data is the only link between statistics, Mother Nature and politics.

It is true as shown in Appendix B that, for $J=6$ tests and 2.571 is the *t statistics* for 6 samples, $\overline{X} \pm W\sqrt{S^2/J} = 1.050S \approx 1S$. The assumed significance is that 6 tests give you μ within $\overline{X} \pm 1S$ at the 95% confidence level and don't cost too much. There is nothing sacred about $1S$ or 95% - these are simply easy-to-digest values accepted by the T&E community; the entire confidence curve resembles an exponential(Appendix B) indicating 3 test confidence minimum.

Probably more valid is the "proper balance of I, J, and K" referred to earlier. Equation 1 can be cascaded forward to accommodate the impact of different test items K, different product lots L, and different scenarios M. It can also be cascaded backwards for the impact of variations in the performance of components, software, etc. Since σ_n^2 is always a function of σ_μ^2 and $\overline{\sigma^2}$, the largest of σ_μ^2 and $\overline{\sigma^2}$ dominates, and that is the one that needs to be reduced, either through more data points per test, or through more tests, or more test items, etc.

It is not valid, therefore, to say that many data points over one test(which covers the I spectrum of very well) covers the J spectrum (results of different tests) at all: I, J, K, L, and M may be (we don't know until we test) mutually exclusive.

Conclusion

This bring us to, "how many tests should we do?" Obviously, more than one, or Equation 1 can't be analyzed. A six test series has nice numbers such a 1, 95, and 6 (1σ, 95%, and 6 tests) and is thus simplistically, probabilistically, and fiscally palatable. But if these tests produce results that look like Case I and II, we haven't determined much. If we have control, we should, by testing, establish the correct values of I, J, etc to minimize σ_n^2.

APPENDIX A

Assume that a test is conducted yielding some performance parameter μ with variance σ^2 from I data points x. Using the definition for σ^2 and μ

$$\sigma^2 = \frac{1}{I}\sum_i (x_i - \mu)^2, \qquad \textit{Equation A-1}$$

$$\mu = \frac{1}{I}\sum_i x_i \qquad \textit{Equation A-2}$$

and expanding Equation A-1 with Equation A-2 substitution generates

$$\begin{aligned}\sigma^2 &= \frac{1}{I}\sum_i x_i^2 - \frac{2}{I}\mu\sum_i x_i + \frac{1}{I}\sum_i \mu^2 \\ &= \frac{1}{I}\sum_i x_i^2 - 2\mu\cdot\mu + \frac{1}{I}I\mu^2 \\ &= \frac{1}{I}\sum_i x_i^2 - \mu^2\end{aligned} \qquad \textit{Equation A-3}$$

which is a restatement of Equation A-1. The use of I instead of $I-1$ in the denominator of Equation A-1 and A-2 is entirely valid for large I ,which simplifies the algebra, and does not detract from the goal of this appendix.

A set of J tests consisting (for further algebraic simplification) of I data points x_{ij} (the j subscript is added to the x_i of Equation A-1 and A-2 to identify which test) produces J sets of μ_j with associated σ_j^2 where

$$\mu_j = \frac{1}{I}\sum_i x_{ij} \qquad \textit{Equation A-4}$$

$$\sigma_j^2 = \frac{1}{I}\sum_i x_{ij}^2 - \mu_j^2 \qquad \textit{Equation A-5}$$

The average $\bar{\mu}$, of the μ_j , and the associated variance σ_μ^2 of $\bar{\mu}$ are

$$\bar{\mu} = \frac{1}{J}\sum_j \mu_j \qquad \textit{Equation A-6}$$

$$\sigma_\mu^2 = \frac{1}{J}\sum_j \mu_j^2 - \bar{\mu}^2 \qquad \textit{Equation A-7}$$

The mean μ_n and associated variance σ_n^2 using all $n = IJ$ data points x_{ij} in one group are

$$\mu_n = \frac{1}{IJ}\sum_{i,j} x_{ij} = \overline{\mu} \qquad \text{Equation A-8}$$

$$\sigma_n^2 = \frac{1}{IJ}\sum_{i,j} x_{ij}^2 - \overline{\mu}^{\,2} \qquad \text{Equation A-9}$$

The simple average of the J variances σ_j^2 obtained from each test is

$$\begin{aligned}\overline{\sigma^2} &= \frac{1}{J}\sum_j \sigma_j^2 \\ &= \frac{1}{J}\sum_j\left(\frac{1}{I}\sum_i x_{ij}^2 - \mu_j^2\right) \\ &= \frac{1}{IJ}\sum_{i,j} x_{ij}^2 - \frac{1}{J}\sum_j \mu_j^2\end{aligned} \qquad \text{Equation A-10}$$

Solving for σ_μ^2 , σ_n^2, and $\overline{\sigma^2}$ as functions of each other, from Equation A-7, A-9 and A-10 yields

$$\overline{\sigma^2} = (\sigma_n^2 + \overline{\mu}^2) - (\sigma_\mu^2 + \overline{\mu}^2)$$

$$\underline{\sigma_n^2 = \sigma_\mu^2 + \overline{\sigma^2}} \qquad \text{Equation A-11}$$

APPENDIX B

$$\mu = \bar{X} \pm W\sqrt{\frac{S^2}{J}}$$

Assume:

$\bar{X} = 0$

$W = $ 95% Level of Certainty

$J = $ Number of Tests

$$\mu = \left(\pm W\sqrt{\frac{1}{J}}\right)S = (Wx)S$$